AN ECONOMIC ANALYSIS OF CRUDE OIL EXPLORATION IN SASKATCHEWAN AND ALBERTA

A Thesis

Submitted to

the College of Graduate Studies and Research

in Partial Fulfillment of the Requirements

for the Degree of

Masters of Arts

in the

Department of Economics

University of Saskatchewan

By

Haul Kamsari

Saskatoon, Saskatchewan

September 2002

To my mother, and the memory of my father

Permission to Use

In presenting of this thesis in partial fulfillment of the requirements for a Postgraduate degree from the University of Saskatchewan, I agree that the Libraries of this University may make it freely available for inspection. I further agree that permission for copying of this thesis in any manner, in whole or in part, for scholarly purposes may be granted by the professor or professors who supervised my thesis work or, in their absence, by the Head of the Department or the Dean of the college in which my thesis work was done. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain will not be allowed without my permission. It is also understood that due recognition will be given to me and to the University of Saskatchewan in any scholarly use which may be made of any material in my thesis.

Request for permission to copy or to make other use of material in the thesis in whole or part should be addressed to:

Head of Department of Economics
University of Saskatchewan
Saskatoon, Saskatchewan, S7N 5A5

Abstract

The International market of crude oil and natural gas is well established and very competitive. Knowledge about costs is important in helping to understand the current position of producers within the industry. In the eyes of the producers, the lower the costs the more profitable they will become given the price of crude.

This thesis focuses on an economic analysis of crude oil exploration in Saskatchewan and Alberta. In a competitive market, the producers require estimates of finding costs in both regions. The public policies that are designed to encourage crude exploration also rely heavily on reliable estimates of these costs.

The results show that Saskatchewan's per-unit finding cost is significantly lower than Alberta's in spite of the geological differences between the two provinces. The finding costs are estimated by using a methodology (Uhler 1979) that has been widely accepted within economic literature of non-renewable resources. The results support the hypothesis that finding costs in both regions are increasing and the argument that these costs will converge in the long-run, except for the last six years of the analysis.

Acknowledgments

Writing this thesis took a longer time than it had been anticipated. I gratefully acknowledge the financial assistance and support from the Department of Economics, University of Saskatchewan. I am indebted to many individuals during the preparation of this thesis. The original idea of the thesis comes from my thesis supervisor, Professor Arne Paus-Jenssen. He has guided me all along, from the program started to its end. I would like to thank him for what he has done. He has shepherded the manuscript of this thesis toward the publication process. The completion of this thesis would not have been possible without his guidance and comments. I also received helpful comments, suggestions, and opinions from my thesis committee. I wish to thank Professor Kien C. Tran, Professor Joel Bruneau, Professor William D. Bishopp, and Professor Hartley Furtan. Their comments have improved this thesis further.

The success of this thesis is also a result of my training as an economist. I would like to thank my Professors whose classes have significantly increased my knowledge in economics. Special thanks to Professor Morris Altman. I enjoyed reading his book and articles. Being his Research Assistant was both enjoyable and rewarding.

Outside the campus, I would like to thank many individuals. Thank you my brothers and sisters for your support and encouragement. Mr. Vernon K. Maxwell has given encouragement and financial assistance during my study. He has become my true friend, I am deeply grateful. Many thanks to many other friends who made my life more pleasurable during my stay in Saskatoon. Thanks to Dung My Nguyen as well as to the Emerald Casino, they provided me with good jobs. Thank you LingJuan Ma, your love and care make my days more cheerful.

Finally, I would like to dedicate this thesis to my mother and the memory of my father.

Table of Contents

List of Tables

List of Figures

Chapter 1

Introduction

The international market of crude oil is well established and very competitive. [1] Large numbers of producers compete to satisfy an enormous demand, [2] implying that the price is determined in the world oil market. In the eyes of producers, the lower the operating costs the more profitable they will become, given the price of crude. Therefore, knowledge about costs is important in helping to understand the current position of the producers. [3]

Canada is part of the international market even though Canada is a small oil producer in the world. The daily crude production in Canada is only 305 thousand cubic meters out of daily 10468 thousands cubic meters world crude production

---

1 Adelman (1972,1990), Wyant (1977), Angevine (1980), Watkins, Adelman, Berndt, Bradley, Greenberg Plourde, Scarfe, Waverman, and Wright (1989).

2 Adelman (1972), Harkness (1984), Helliwell, MacGregor, McRae, and Plourde (1989), Shojai and Katz (1992).

3 Hubbert (1962), Fisher (1964), Adelman (1972, 1988, 1990), Epple (1975), Eglington (1975), Uhler (1976, 1979, 1985, 1986), Devarajan and Fisher (1982), Eglington and Uffelmann (1983), Bradley (1984), Scarfe and Rilkoff (1984), Livernois and Uhler (1987), Tanner (1987), Livernois and Ryan (1987), Livernois (1988), Cuddington and Moss (1998).

during 1999; [4] smaller than 3% of the total world production. The established reserves in Canada during that year are even less significant at 769 billion cubic meters of total 165,830 billion cubic meters world oil reserves. [5] This is less than 0.5% of the world reserves.

Saskatchewan and Alberta are the main oil producing provinces in Canada with approximately 28% and 58% of the total national production. [6] The main market for oil produced in both provinces is the North American market (Canada and USA). However, the global market connections exist through an elaborate system of pipelines and through railway or ocean shipping (tankers). These linkages connect both regions to the international oil market and the industry.

The process of supplying oil is complex, and involves several steps, each of which is costly and time consuming. The economic analysis of supply process suggests that the major steps are:

---

4 ***Energy Statistic Handbook***, Statistic Canada, Natural Resources Canada, CD Rom - May 2001, and ***CANSIM Catalogue Files*** <http://datacentre2.chass.utoronto.ca/cansim/catalogues.html>, matrix number E8600 and E8616.

5 Ibid.

6 Source: ***Statistic Canada***, catalogue 26-213-XPB,1999.

1. Exploration(finding) activities
2. Development activities
3. Production activities
4. Transportation activities

Each of these steps involves costs. The cost of exploration, or finding cost, is the cost of finding new oil. This is important because it provides crucial information for investment decisions. Many studies in petroleum economics conclude that exploration cost is a significant cost of the total cost (development cost, transportation cost, production cost, etcetera) in the industry. [7] Of those, most expenses tend to be allocated on the first two steps, exploration (finding) and development activities. The scope of this study will only be the exploration activities.

One peculiar problem faced by every producer is the scarcity problem. It will be increasingly difficult to find 'new oil' in the future. 'Difficult' means delays in exploration activities, and a delay can be very costly. 'Difficult' can also mean more efforts required to drill. The deeper a pool to be drilled, the costlier a project will be. Both will cause an oil company to dig into its purse even deeper.

[7] Fisher (1964), Epple (1975), Eglington (1975), Pindyck (1978), Uhler (1976, 1979), Devarajan and Fisher (1982), Eglington and Uffelman (1983), Bradley (1984), Scarfe and Rilkoff (1984), Livernois and Ryan (1987), Livernois (1988).

Therefore a 'difficult' exploration will tend to drive costs upward and can be portrayed as an increasing cost curve in Figure 1.1.

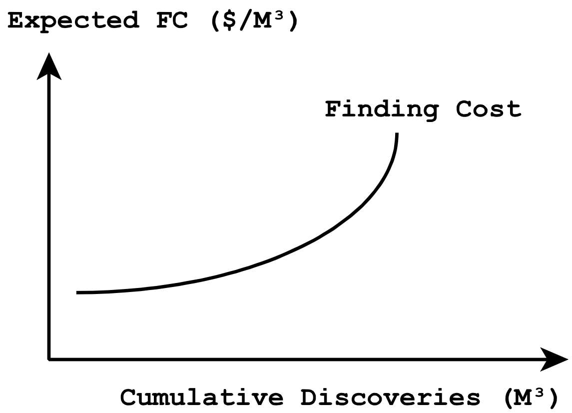

Figure 1.1: Expected finding cost

In the literature of Petroleum Economics this curve is frequently called the Supply Curve of Discovery. It is the locus of the short-run marginal cost of each new discovery.

There are significant differences in geophysical and geological structures between the two provinces. Geological studies suggest that the crude accumulations in the tectonic elements in Saskatchewan are smaller than they are in Alberta, [8] implying a smaller amount of oil in place estimates. Less oil in place implies lower reserves. The

[8] Mossop G.D., ***Geological Survey of Canada***, Calgary, <http://www.ags.gov.ab.ca/ags_pub>.

reserves in both provinces are dispersed within the Western Sediment Basin. The basin captures large area of Alberta and only the south part of Saskatchewan.

The total land areas of the two provinces are approximately the same. These totals are divided into the tracts for exploration purposes. Since the Western sediment basin captures a smaller land area of Saskatchewan than Alberta, it is not surprising that there are fewer discoveries and successful tracts in Saskatchewan compared with Alberta. Porter and Hendricks, for example, suggest that there is very high probability of finding new significant oil fields in the neighbouring tracts of those which have been previously successful. [9] In other words, the study suggests that one would expect a lower chance to find 'new oil field' that is economically significant in Saskatchewan relative to Alberta.

Public policies will also affect the economic incentives through costs. For the sake of economic analysis in the two producing regions, the impact of public policies on costs will be compared and examined as well. Suppose the public policies in Saskatchewan and Alberta do not differ significantly. With fewer expected new discoveries in Saskatchewan, oil producers will generally expect exploration

---

9 Porter, R. and K. Hendricks, "Determinants of the Timing and Incidence of Exploratory Drilling on Offshore Wildcat Tracts", ***American Economic Review***, vol. 86, 1996, P. 388-407.

activities in Saskatchewan to be less successful than exploration activities in Alberta.

Finding cost (FC) is defined as the cost of finding one cubic meter of new oil. Given the total cost of exploration, the expected finding cost will depend entirely on the expected discoveries. The expected new oil discovery in Saskatchewan is lower than it is in Alberta, therefore the short-run (current) Saskatchewan's finding cost is expected to be higher vis-à-vis Alberta's. Accordingly, the producers' expectations of finding costs in Saskatchewan and Alberta can be described in Figure 1.2.

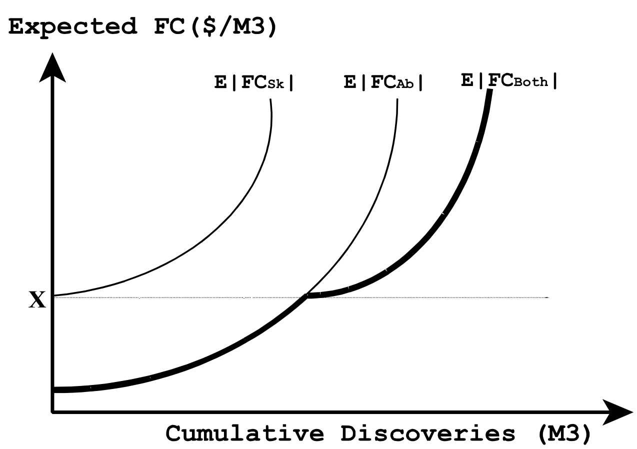

Figure 1.2: Producers' finding cost expectations in two producing regions

Economic theory suggests that all producers are profit maximizers. The producers are assumed to be aware of economic incentives from exploration. They will choose the most promising area that is expected to contain a significant amount of oil and gas reservoirs, and that is economically profitable. [10] Saskatchewan and Alberta are neighboring provinces within a national border. Inputs are expected to be mobile, except for the land input. Economic theory suggests that firms (producers) operating in competitive input markets will act quickly to exploit profitable opportunities. When the producers realize that finding cost in one region is lower than the other, they will be expected to move their exploration activities to the lowest cost region. More activities in that region will normally cause the finding costs to increase. Ultimately, the finding costs in that region will increase at an increasing (higher) rate compared with the higher cost region. Once the expected FC reaches $ X per-cubic meter, at which the expected FC for both provinces are equal, finding activities will also occur in Saskatchewan. In aggregate, the expected FC for both provinces is illustrated as bold curve in Figure 1.2.

10

Even though it is more likely that the most promising area is the area where most discoveries being made, the quote that the area is the most economically profitable is misleading because of the expenditure of extracting final products in that area can be more costly at the margin (per-cubic meter).

The hypotheses in this thesis is then the following:

1. Unit finding costs in both provinces are expected to increase [11] due to resource scarcity problems. [12]
2. In each region, finding cost will increase at different rates due to the differences in geological structures, land areas, public policies, finding expectations, etcetera.
3. Saskatchewan's per-unit finding cost is expected to be higher than Alberta's because the quantity of oil discoveries in Saskatchewan is expected to be lesser than in Alberta.
4. However, the profit-maximizing behaviour of the producers suggests that finding costs in both regions will converge in the long-run.

Uhler's methodology will be used to estimate the finding costs in both regions. Once the empirical results are estimated, they will be compared and analyzed to see whether or not they behave as expected in the two regions.

Chapter 2 begins with the background of crude oil and natural gas in Saskatchewan and Alberta. In Chapter 3, the

---

11 Hotteling (1931), Hubbert (1962), Fisher (1964), Adelman (1972, 1990), Pindyck (1978), Uhler (1976, 1979), Devarajan and Fisher (1982), Livernois (1988).

12 Hotteling (1931), Hubbert (1962), Fisher (1964), Adelman (1972, 1990), Uhler (1976, 1979), Devarajan and Fisher (1982), Livernois (1988).

discussions are on the review of literature. Chapter 4 presents estimations and empirical results. The methodology of estimation is based on Uhler's 1979 model, modified with references to Eglington 1975, Eglington and Uffelmann 1983, and Livernois 1987. The causes of finding cost differences between the two regions are discussed in Chapter 5. Conclusions are drawn in Chapter 6.

Chapter 2

The Background of Crude Oil in Saskatchewan and Alberta

2.1 Crude Oil Discoveries

Saskatchewan's first commercial crude oil production occurred in 1944 in Lloydminster. The discovery of the Midale oil field in the southeast in 1953 was a big step toward modern crude oil exploration in Saskatchewan. Intensive exploration efforts in the mid 1950s and early 1960s led to the discoveries of many major pools in the province. The Crown holds approximately 75% of oil and gas rights in Saskatchewan, and these rights are leased to private companies for development and production. The remaining 25% of the oil and gas rights are privately owned and generally available for leasing. Oil and gas are produced from reservoir rocks ranging in age from Ordovician to Cretaceous.

As presented in Table 2.1, before 1953 there were less than 500 wells drilled in Saskatchewan, compared with 6,016 active wells in 1969. In 1979 there were 8,071 active wells and 9,588 wells capable of production. Total production of crude was less than five hundred thousand cubic meters (M^3) in 1953. It increased to 13.89 million M^3 in 1969, but decreased to 9.37 million M^3 in 1979.

Table 2.1: Oil wells and yearly production in Saskatchewan, selected years [13]

Year	Active Wells	Wells Capable of Production	Crude Production (000 M^3)	Average Prod./Well (000 M^3)
1953	454	760	444	0.98
1969	6,016	7,096	13,891	2.31
1979	8,071	9,588	9,372	1.16
1989	13,880	18,982	11,696	0.84
1997	18,856	27,013	23,460	1.24

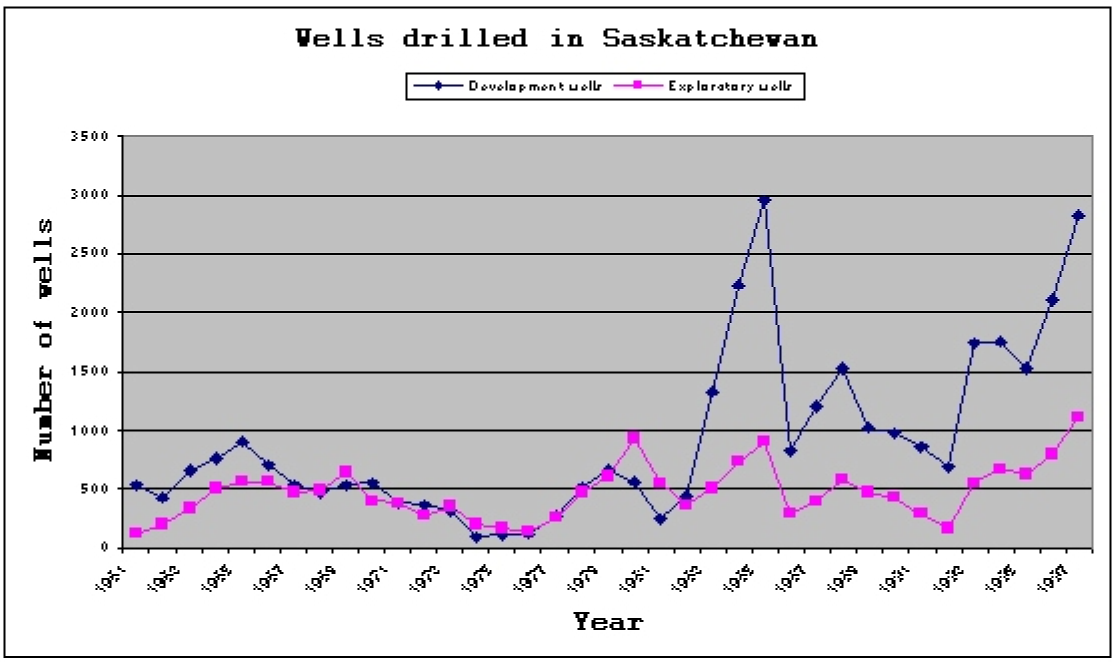

Figure 2.1: Wells drilled in Saskatchewan, 1961-1998 [14]

---

13 Source: Saskatchewan Energy and Mines, ***Mineral Statistics Yearbook***, 1999, P. 219-220.

14 Source: ibid.

Alberta's first natural gas discovery was made in Langevin, near Medicine Hat in 1883. In 1902, crude oil was produced for the first time at the Waterton Lake National Park. Later seven wells were drilled around Medicine Hat. Activities moved to Bow Island in 1909. In 1914, the oil and gas industry 'fever' in Calgary caused the stocks in oil and gas exploration industry to surge. It came to an end in 1917 when many exploration companies declared bankruptcy. Another significant discovery was made in Turner Valley in 1924 by the Calgary Petroleum Products Company. Exploration activities kept flourishing until 1936 in this area.

In 1947, a major discovery of light oil in Leduc, south of Edmonton, by Imperial Oil placed Alberta nationally and internationally on the map as a major crude and gas producing region. The huge discoveries continued after 1947 in Pembina, Gillwood, and Rainbow-Zama, and have made up a great oil and gas cumulative discoveries in Alberta.

Table 2.2 presents the growth of drilling activities conducted in Alberta, and Figure 2.2 shows the historical exploration activities and development activities in that province.

Table 2.2: Oil wells and yearly production in Alberta, selected years [15]

Year	Active wells	Wells Capable of Production	Crude Production (000 M³)	Average Prod./Well (000 M³)
1953	1,361	4,454	12,190	8.96
1969	1,950	14,000	39,850	20.44
1979	5,780	17,673	68,483	11.85
1989	n/a	n/a	73,979	n/a
1997	39,493	89,640	55,491	1.40

Note: Tar sands are excluded

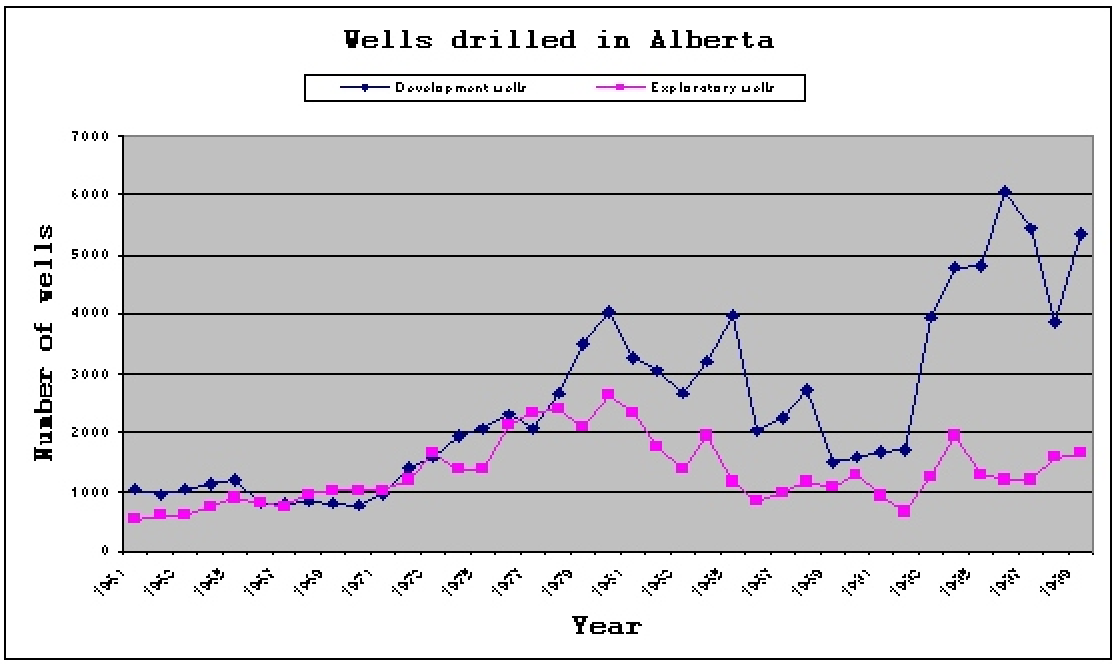

Figure 2.2: Wells drilled in Alberta, 1961-1998 [16]

---

15 Sources:
(1) ***ERCB Annual Statistic***, 1985, p. 61.
(2) ***ERCB Annual report***, <http://energy.gov.ab.ca/bbs/news/newsreel/1999/nr99-11.htm>.
(3) Crude Oil and Gas Disposition, ***Statistic Canada***, 26-213-XPB, 1999, p. 2.

16 Sources: ibid.

A comparison of the aggregate activities between the two provinces is possible with reference to Tables 2.1 and 2.2. In 1979, around 84% of oil wells capable of production were active in Saskatchewan, but only around 33% for Alberta. The average production per well, however, was much larger in Alberta. Intuitively speaking, even though capable, the in-active wells indicate that these wells must be operated uneconomically. Ordinarily, should the wells contain enough oil to generate profits they would have been activated. In other words, the costs to operate these wells must be higher than the total value of outputs in order for them to be left abandoned. Assuming each well requires equal cost of exploration, a smaller proportion of active wells also implies a costlier process, therefore the oil wells in Saskatchewan must be operated more economically efficient compare with the oil wells in Alberta (Chapter 4).

2.2 Crude Oil Reserves

There are many definitions of reserves in the oil industry. Oil in place is an estimate of the volume of crude in the ground. Part of this estimate is recoverable, but some is not. The recoverable crude in the ground is called initial recoverable reserves. Some of these reserves have already been established, and that called initial established reserves. The remaining reserves are then calculated by subtracting the initial established reserves from yearly production plus reserve additions during that year.

Reserve additions come from several sources: [17] discoveries of new reservoirs; development of old reservoirs; reproduction and extension of known reservoirs; [18] and adjustment and revision of the in-ground values of those known reservoirs.

Historical data shows that yearly estimates of remaining reserves of crude for both provinces from 1971 to 1999 are fairly stable. Whether the yearly estimates of remaining reserves raise or fall will depend on the rates of reserve additions and productions. When the rate of production grows faster than the rate of reserve additions during one particular year, the remaining reserves fall.

Alberta reserve additions peaked during the 1960s. This peak was a result of the cumulative discoveries of large basins in Alberta, such as Leduc (1947), and immediately followed by discoveries of other plays: Pembina, Swan-Hills, Gillwood, and Rainbow-Zama. These discoveries caused the cumulative oil and gas reserves in Alberta to increase rapidly. They also attracted more producers to try their luck in Alberta.

---

17 See: Uhler (1979), Bradley(1984).

18 For example: economic reason, political reason, etc.

Figure 2.3 shows that reserve additions in Saskatchewan are mainly from development and extension of old reservoirs.[19] Tanner believes that at least 80% of all oil in the ground had already been discovered in Saskatchewan.[20] While Figure 2.4 shows that Alberta's reserve additions from new discoveries were fairly stable, relative to its reserve additions from an extension of old reservoirs.

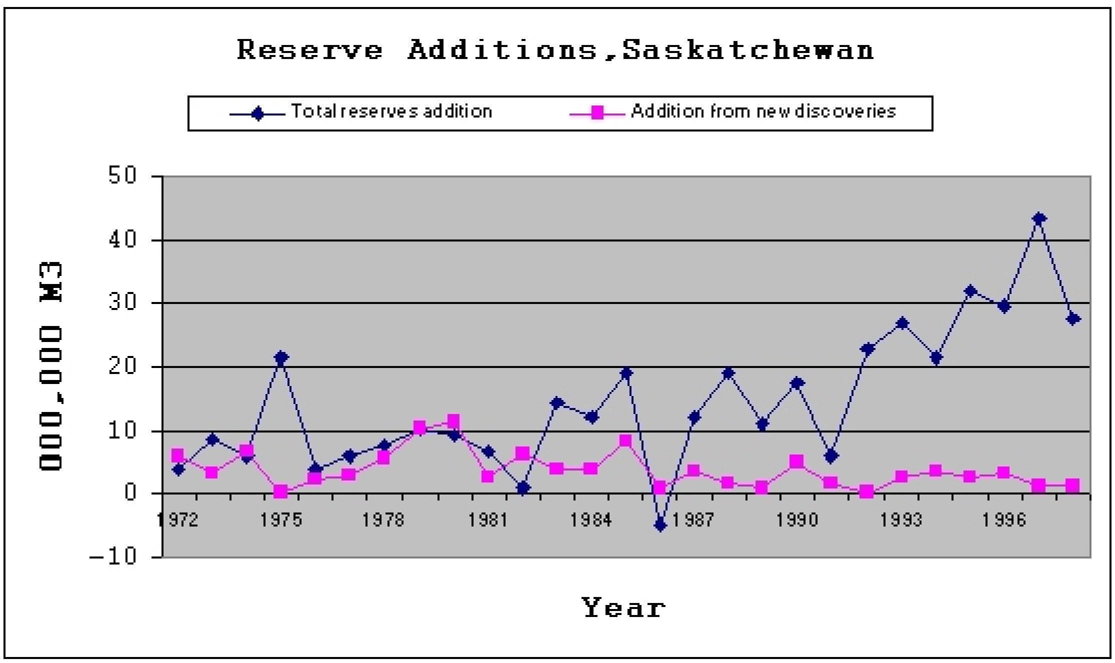

Figure 2.3: Reserve additions - Saskatchewan, 1971-1998 [21]

19 Saskatchewan data is taken from ***Reservoir Annual - Saskatchewan Energy and Mines***, and Alberta data is taken from ***ERCB Reserves***. Reserves addition is approximated by subtracting total yearly production to the change in remaining reserves during particular year.

20 Tanner, J.N., "***An Evaluation of Crude Oil Supply In Saskatchewan***," Study no.25, Canadian Energy Research Institute, 1987, p.51.

21 Source: Saskatchewan Energy and Mines, ***Reservoir Annual***, 1971-1999, p. C-1.

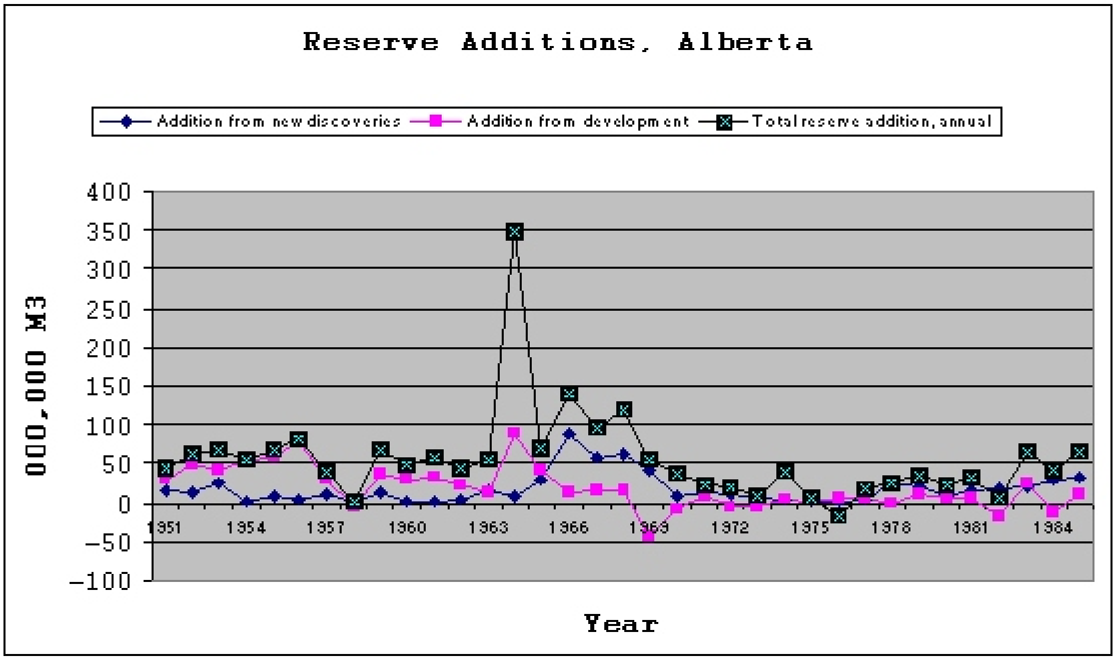

Figure 2.4: Reserve additions - Alberta, 1951-1985 [22]

2.3 Crude Oil Prices [23]

The market price of crude will determine the economic incentives from exploration. The higher the price the higher is the in-ground value of crude. A high in-ground value of crude implies greater incentives to find new oil. Assuming that producers are profit maximizers, they will conduct more explorations. In this thesis, the average cost of imported crude into Montreal will be used as a benchmark market price

---

22 Source : ***ERCB Reserves***, 1985, Table 8-1, p. 8-2.

23 As noted by Professor Adelman (1972), there are three kind of prices in economic theory:1)The Market Price; The current rate of exchange of money against goods, 2) The Competitive Supply Price; The least that need to be paid to bring forth the stream of output, and 3)The Reference Price; The expected revenues that will exceed or at least equal the competitive supply price (***The World Petroleum Market***, P.195-196).

for international crude. This price is similar to the price in the international market, the US-refiner acquisition price of imported crude from Canada and elsewhere. In Saskatchewan and Alberta, the average wellhead price will be used as the Canadian market price. Because of the National Energy Program (NEP) introduced in the 1970s, the Canadian market price was set below the international market price (see Figure 2.5).

Professor Adelman suggests the competitive supply price consists of the costs of supplying oil. There are many categories of costs involved in the process of supplying oil (Chapter 1). This price also determines the producers' profits. A lower supply price will yield a higher profits to the producers. Since finding costs are included in the competitive supply price it is important to include this price in an economic analysis.

Professor Adelman also introduces the concept of reference price. It is a measure of the expected revenues that must exceed or be equal to the supply price. The reference price, then, should fall somewhere between the competitive supply price and the market price. When the reference price is lesser than the supply price, no producer would like to supply crude oil.

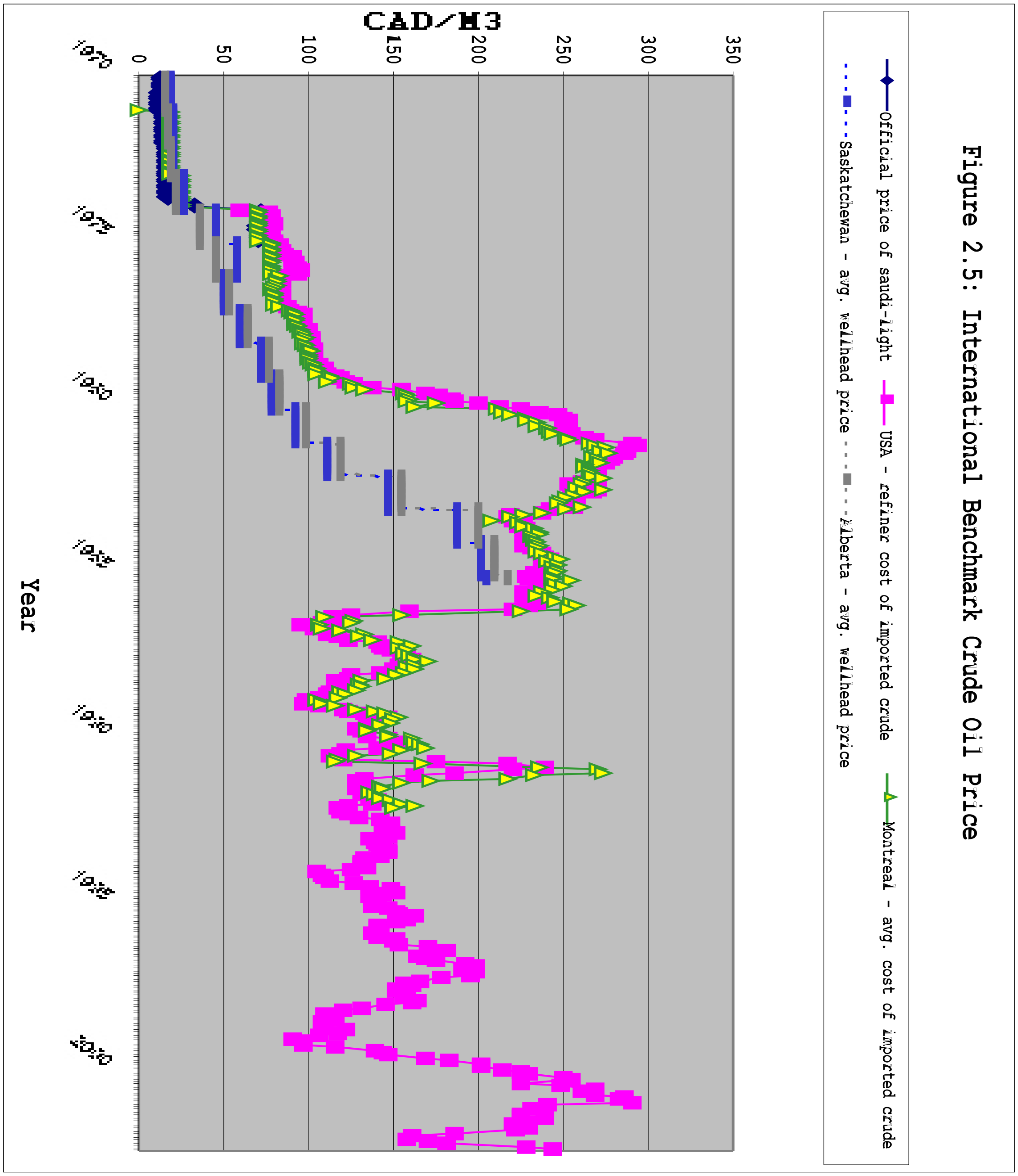

Figure 2.5: International crude oil prices [24]

24 Sources:
1. Government of United States website: <http://www.eia.doe.gov/emeu/cabs/crhon.html>.
2. CANSIM catalogue files, <http://datacentre2.chass.utoronto.ca/cansim/catalogues.html>. Label: E313018.
3. ***ERCB Annual Statistic***, 1985, p. 8 and 9.
4. Saskatchewan Energy and Mines, ***Mineral Statistics Yearbook***, 1999, p. 75.

2.3.1 Historical Background of Crude Price: The Three Eras

The trends for oil prices in both provinces follow world events closely. As presented in Figure 2.6 (as well as in Figure 2.5), the historical data suggest that the price behaviour can basically be divided into three eras; the stable price era(1945-1972), the rising price era(1973-1985), and the volatile price era(1986-present).

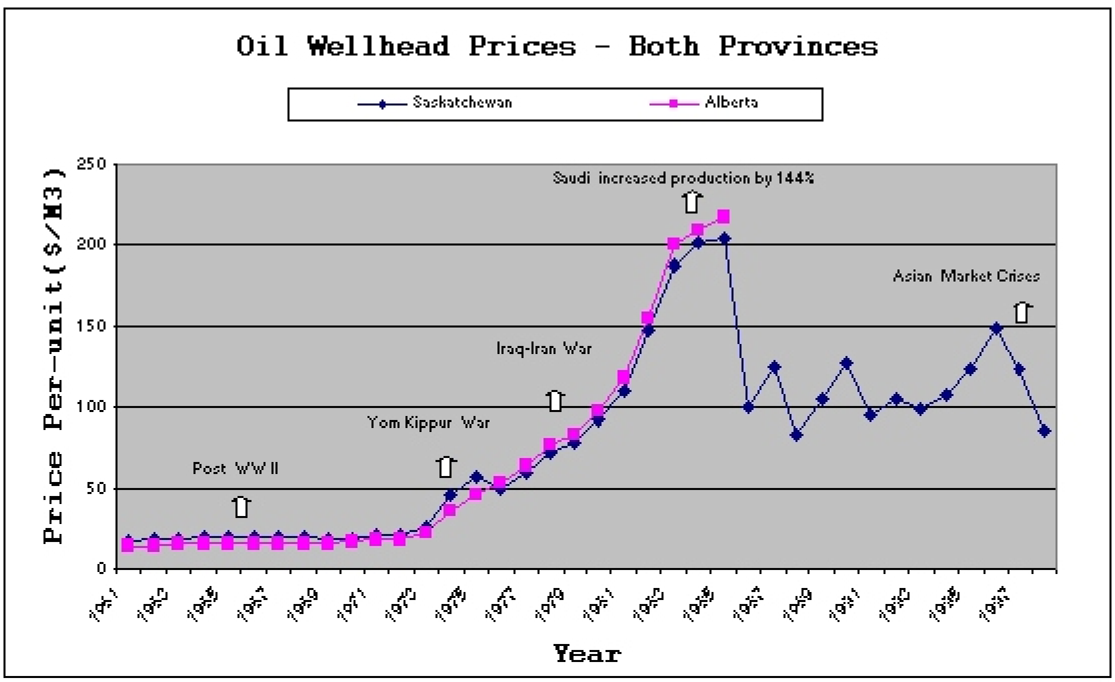

Figure 2.6: World events and oil wellhead prices in Saskatchewan (1961-1998) and Alberta (1961-1985) [25]

---

25 Sources:
(1) ***ERCB Annual Statistic***, 1985, p. 8 and 9.
(2) Saskatchewan Energy and Mines, ***Mineral Statistics Yearbook***, 1999, p. 75.

Stable Oil Prices: 1945-1972

After the World War, the crude wellhead prices were fairly stable at about CAD 15/M^3 from 1950s to the end of 1971. The price started to increase in 1972, declined slightly at the end of the year, and rose consistently until the end of 1985.

Rising Oil Prices: 1973-1985

An increasing price started when Yom Kippur War and Arab Oil Embargo began. The war was started shortly after Syria and Egypt attacked Israel on October 5, 1973. The result was a significant change of crude price in the world. The crude wellhead prices in Saskatchewan and Alberta were CAD 20.28/M^3 and CAD 17.99/M^3 respectively in 1972, and rose to approximately CAD 40/M^3 shortly after the war.

Another war, the Iraq-Iran War has led to another enormous increase in world crude price between 1979 and 1983. The combination of the Iranian revolution in 1978 and the sharp loss of crude production in Iraq in 1980 had resulted in more than doubling of crude price in both provinces in 1983.

Beside the warfare, collusion is another reason of rising price in the 1980s. As the biggest oil cartel in the world, OPEC clearly has some control over world oil price. In an attempt to increase the degree of monopoly, its members set a tacit production quotas in 1982. The objective of this policy was to stabilize the high crude price. Unfortunately this attempt was not successful because some of the members violated the tacit collusion by producing oil beyond their quotas. Crude productions in non-OPEC countries also rose, for example: in United States, Canada, Norway, Russia, China, United Kingdom and Mexico.

Saudi Arabia has played a dominant role in OPEC. Saudi Arabia led OPEC countries to stop the crude price from falling by cutting its production in 1984. It finally gave up in 1985 because the loss of its petroleum share over national income was too large. The price started to decline, and has fluctuated since.

Volatile Oil Prices: 1986-present

By the early 1986, the Saudis increased their production by around 144% from roughly two million barrels to approximately 4.9 million barrels per day. This led to sharp decreases in world crude prices. However, the combination of warfare in the Middle east and OPEC policies caused a 'roller-coaster' in crude price in the late 1980s and early 1990s. Another event is the end of Iraq-Iran War. This stimulated more production in the Middle East and led to another sharp decrease in crude price to roughly CAD 80/M^3 in 1988. When Iraq invaded Kuwait there was another jump in crude prices in 1990. Prices decreased when Iraq was defeated.

Crude prices were stable from 1991 to 1994. In 1995, the booming economy in Asia and the strong economy in USA increased the demand for crude and led to higher crude price. But markets are subject to risks. Emerging financial market crises in Asia happened at the same time when OPEC increased its production quotas by 10%. This combination led to a decrease in crude prices in 1998.

The Asian market recovery and a strong American economy in 1999 again led to high demand for crude oil and record high crude price at CAD 203/M^3. The recent September 11th incident led to another significant fall of the crude price in both provinces. [26]

In summary, prices in the local market follow the crude price in world markets. As noted in chapter 1, under current competition condition the local market is connected to the national and the international markets. The connection among these markets clearly depend on the ease of transportation of crude. The degree of 'openness', however, not only depends on the connection to the world markets, but also depends on the regulations by authorities.

---

[26] Refer to 'Crude Oil Market Alert', Canadian energy experts (Vincent Lauerman - CERI, Andrew Thompson - Saskatchewan Minister of Energy, Patricia Nelson - Finance Minister, Government of Alberta) predicted large drop in crude oil price in the local market, Alberta and Saskatchewan ..... Finance Minister said making spending decisions for 2002 will be more difficult, ***The StarPhoenix***, November 1st 2001, p. C1 and C5.

2.3.2 Prices and Transportation of Crude

There are several ways of transporting crude from one region to another: ocean shipping, barges, railways, or pipelines. This will enable oil producers to place crude in the local or the international market. Crude transportation also requires costs.

Transportation costs vary depending on the situation and condition of placing crude into a market. When supplies are plentiful, most of these costs are borne by producers. They will sell oil at low profits or even at short-term loss. When demand is strong most of these costs are borne by consumers.

The profit maximizing producers will choose the most efficient combinations of transportation. To maximize profits one must minimize costs. The least cost process is always preferred, regardless of demand conditions. If the desired market can be reached by pipelines, then this route will be chosen because it will yield cheaper cost of transportation in the long-run.

In the 1950s, crude supply from western Canadian producers increased quickly. The quantity of crude oil produced exceeded demand in the regional market. In order to sustain the expansion, an easy access to a larger market was required. The larger market was deemed to be the North

American market (Canada and USA). The largest markets were located in/around Chicago and Ontario. Crude oil from Western Canada could be transported by pipelines to most of consumers in the North American market.

Canadian government initiated action in the late 1950s by building pipelines that would connect the producers in Saskatchewan and Alberta to central North America. The debate over petroleum pipelines during the 1950s and the early 1960s was whether to build an open market to 'all Canadian routes' (pipelines from Western Canada to Ontario-west of the Ottawa Valley) or to built the 'routes to the South' (pipelines toward Midwest industrial area-Chicago market, in the USA). The access to the larger market exposed regional producers to price competition from imported crude. In the early 1960s the Canadian government protected Western Canadian producers by reserving Canadian markets to the west of the Ottawa Valley for domestic producers. The consequence of this policy was to exclude foreign crude products from the Ontario market and reserving it for Saskatchewan and Alberta producers. This policy benefitted the domestic producers in the mid 1960s, and the crude oil productions in both provinces increased rapidly. From 1961 to 1969, crude productions in Saskatchewan and Alberta increased by around 57% and 91% respectively. [27]

[27] Source: ***Statistic Canada***, "Supply and Disposition of Crude Oil," catalogue 26-213-XPB,1951-1999.

2.4 Public Policies

Both federal and provincial governments can intervene in the oil industry in many ways. The oil industry in Canada has experienced three most prominent roles of the government through its policies, namely, the crude oil price control during the 1980s, the government control through the access to reserves, and the control through royalties or production taxes. All have significantly affected the crude explorations in Saskatchewan and Alberta. The subsections below will discuss these public policies and how they may affect the crude oil exploration in both regions.

2.4.1 The Price Control

The crude prices are closely related to the national economy. Following the first round of OPEC oil price increases in 1973, the crude prices in all international markets increased, including in Canada and the United States. In 1974 and 1975, the inflation rate in Canada increased by 10% and 7% respectively. [28] In 1975, there was an attempt to control the wages and prices by issuing the Anti Inflation Act. In addition, the Canadian government set the price of crude produced in Canada below the international price of crude.

---

[28] Minister of Supply and Services Canada, ***Canada Year Book 1985***, Catalogue No. 11-402E/1985, The Bryant Press Limited, Ottawa, 1985, p. 367.

In 1982, a new Federal-Provincial Oil Pricing Agreement was made. This agreement attempted to encourage domestic crude exploration by allowing producers who find 'new oil' to sell the product at CAD 278/M^3. This was above the international market price. The cost of importing crude into Montreal was CAD 201/M^3. The price of 'old oil' (produced from wells completed before 1981) was set at CAD 162/M^3. The difference between the two reference prices was thus then CAD 116/M^3. This left strong incentives to the producers in Alberta and Saskatchewan to conduct more crude oil exploration activities. This created 'exploration frenzies', and therefore the aggregate expenditures in both regions, especially in Alberta.

2.4.2 Controlling Access To Reserves

The provincial governments' involvement in oil exploration is also by regulating access to reserves and by setting royalty rates on production from new discoveries. Governments argue that the objective of these interventions is to encourage more exploration activities, though is often extended to other objectives such as economic stability, rate of employment, labor income distributions, and oil supply. But before analyzing a specific issue of public policies it will be helpful to understand the process of oil finding that underlies these policies.

The finding process of reserves involve the usual inputs; labour and capital. The recruitment process of labour starts from the hiring of land surveyors; geologists and geophysicists, to the hiring of field workers; derrick men, roughnecks, equipment's operators, field supervisors, and petroleum engineers. A more complex structure of labour in the industry also includes overhead workers, office helpers, sales persons, managers, directors, consultants, and economists. The acquisition of capital starts from the purchasing of licences or rights, equipments, buildings to the bidding of lands or tracts. For the sake of simplicity, this complex structure is usually divided into three main categories of inputs; geophysical activity, drilling activity, and land acquisition.

In Canada, the oil and gas industry is influenced by both federal and provincial governments. Each government regulates inputs in different ways. To understand the governments involvement in the industry it will be useful to discuss how these regulations originated.

Government Policies on Drilling and Geophysical Inputs

Drilling and geophysic inputs both involve both labour and capital, but mostly labour. While each province can set their minimum wage for labour, The British North America Act does not restrict the mobility of labour and equipment located in the province.

It is also quite impossible for the Crown to make out-of-province workers pay more income tax than the workers from the province origin. In this case then, the two inputs will be very mobile, and the input markets will somehow achieve their equilibrium level by Adam Smith's invisible hand. [29] For example: if roughnecks' salaries in Saskatchewan are below the salaries paid to those in Alberta, then more productive roughnecks will work for oil companies in Alberta.

Government Policies on Land Input

The case for land input is different from the other two inputs. Land is immobile and is completely dominated by the provincial government. The British North America Act clearly states that all non-renewable resources will be controlled exclusively by each province. Almost the entire land input consists of capital investments. Even though overhead expenditures exist, the amount is relatively small compared with the total investment on land. Overhead costs can therefore be ignored. The land input is therefore assumed to consist of the Crown rights sales for oil drilling purposes only.

29 Smith, A., "***An Inquiry into the Nature and Causes of the Wealth of Nations***", New York: Modern Library, 1937.

There are two types of land tenure systems for the purpose of oil and gas exploration and production: the crown and the freehold exempt. The crown exempt category is mandated by the Crown Mineral Act while the freehold exempt category by the Freehold Oil and Gas Production Tax Act. The land rights sale system is done by auction. The forms of these land sales are: Special Agreements, Special Exploratory Permits, Exploration Licences, Permits, Leases, and Drilling Reservations.

In Saskatchewan and Alberta, the Crowns conduct land auctions six times or more a year. The standard rules of public auction apply to this process and formally follow The Crown Mineral Act and The Petroleum and Natural Gas Regulation (1969). The Crown will start 'the bottom-rock' price based on the information released during the auction. The bidders of these rights are the oil producers and the winner [30] of an auction is of course the one who bids the highest. The more reliable the information on a specific land the more precise the investment made by the producers in terms of risk and return. The final price of the land will then be determined and the right is sold. At the end of the day, the Crowns will earn revenues.

---

30 As mentioned by Professor Thaler, an anomaly in oil industry is that the winner of an auction is often a loser, in a sense that no one know exactly how much oil is in the ground. See Thaler, R.H, "***The Winner's Curse***", The Free Press, Macmillan, New York, 1992.

Table 2.3 presents information on the area leased and the revenues collected from land auctions in both provinces. Land acquisition activities peaked in the late 1960s and the early 1970s, just when the price of crude oil in the world markets started to increase. Fewer auctions were conducted in Saskatchewan and more land acquisitions took place in Alberta. As a result, Alberta's land price per hectare is always valued more than Saskatchewan's (by around $50 per-hectare, on average, in the 1980s and the 1990s). More explorations were conducted in Alberta suggests that the producers believe that there is more oil trapped in the sedimentary rocks in Alberta. In other words, the producers would expect a better returns by conducting crude oil explorations in Alberta, compared with Saskatchewan.

Table 2.3: Area leased and revenues collected from land auctions in Saskatchewan and Alberta, selected years [31]

year	**Saskatchewan** (1)			**Alberta** (2)&(3)		
	Area (000.Ha)*	**Revenue ($.mil)**	**Revenue/Ha (approx.)**	**Area (000.Ha)***	**Revenue ($.mil)**	**Revenue/Ha (approx.)**
1953	189	2.7	14.3	n/a	n/a	n/a
1969	1903	4.9	2.6	29021	163.4	5.6
1980	228	77.6	340.3	2474	1004.9	406.2
1997	934	131.0	140.3	4784	970.0	202.8

Note: * including PNG rights sales of drilling reservations, permits, and leases.

31

Sources:
(1)Saskatchewan energy and mines, ***Mineral Statistics Yearbook***, 1998, p. 187.
(2)Alberta Bureau of Statistics, ***Alberta Statistical Review Annual***, 1973, p. 66.
(3)***Energy Alberta***, Annual Report, <http://www.energy.gov.ab/com/time/PNG+sales/public+sales /public+sales/total+-+1999.htm>.

2.4.3 Royalties and Taxes

The Crowns own the crude oil and natural gas in the ground. They decide whether to produce crude oil and gas through their own corporation, or to sell rights to the private producers. The relation between the Crowns and the producers are best described as principal-agent relation. [32] The Crowns collect revenues from royalties and taxes paid by the producers. Both provincial governments' revenues from royalties and production taxes are presented in Table 2.4 and Table 2.5.

Table 2.4: Saskatchewan provincial revenues from oil royalty and production taxes, all types of crude, 1980-1985 [33]

Year	Revenue from Oil Royalty (Mil.$)	Value of Oil Production (Mil.$)	Percentage Revenues of the Value of Production (%) **
1980	386	860	44.9
1981	334	818	40.8
1982	388*	1186	32.7
1983	513*	1646	31.2
1984	518*	1863	27.8
1985	547*	2241	24.4

Notes:
* Excluding oil exports tax of 349.08 millions for 1982, 54,95 millions for 1983, 85,35 millions for 1984, and 66.14 millions for 1985.
** Net After rebates

32 As states in ***The Constitution Act*** (***The British North America Act***), 1867, Non-Renewable Natural Resources, Forestry Resources and Electrical Energy : ...92A. (1) In each province, the legislature may exclusively make laws in relation to (a) exploration for non-renewable natural resources in the province;...4) In each province, the legislature may make laws in relation to the raising of money by any mode or system of taxation in respect of (a) non-renewable natural resources and forestry resources in the province and the primary production therefrom.

33 Source: Saskatchewan Energy and Mines, ***Mineral Statistic Yearbook*** 1999: p. 11 and 74.

Table 2.5: Alberta provincial revenues from oil royalties and production taxes, all types of crude, 1980-1985 [34]

Year	Revenue from Oil Royalty (Mil.$)	Value of Oil Production (Mil.$)	Percentage Revenues of the Value of Production (%) **
1980	1970	6919	28.5
1981	2180	7504	29.1
1982	2339	9264	25.3
1983	2883	10826	26.6
1984	3100	11661	26.6
1985	2700	12209	22.1

Note: ** Net After rebates

Table 2.4 and Table 2.5 show the aggregate amount of oil royalties collected by the Crowns as a percentage of the values of production. The tables indicate that Saskatchewan's royalty rates are consistently higher than Alberta's rates during the 1980s. The difference of the revenues collected as a percentage of the value of production in Saskatchewan and Alberta ranges between 2% to 16%. From 1982 to 1985, the recorded data for Saskatchewan includes the federal oil export tax. In the table itself the oil export tax is excluded since this tax is charged by the federal government, not the Crowns.

The question why these royalties differ is not explored. The level of royalty and tax rates are determined by the governments. As the price of crude in the world market

[34] Source: Alberta Dept. of Energy and Natural Resources, ***Annual Report*** 1985, p. 6.

change, the producers' incentives from producing oil will change. As the incentives from producing oil change, the level of activities will also change, depending on the new level (higher or lower) of the world crude price. The Crown normally takes this opportunity by charging the producers higher or lower royalty rates accordingly, and receive some optimum revenues. To support this argument, let us examine more closely on how the royalties and production taxes are determined.

There is a branch of the Crowns energy division that will take an active role in discussion with oil industry and the federal government on taxation and other matters affecting the economic performance of the industry. In Saskatchewan, the Energy Division of the Saskatchewan Energy and Mines [35] recommends the level of royalty rates levied on the producers during the year. In Alberta, the Policy Analysis and Planning Division in co-operation with other divisions and agencies of the Alberta Energy Conservation Board will perform this task. [36]

---

35 Source: Saskatchewan Energy and Mines, ***Annual Report***, (1982/1983: p. 11), (1983/1984: p. 11-12), (1984/1985: p. 11-12), (1985/1986: p. 9-10). It is clearly stated: "... the Branch involves in the development of a new royalty and taxation system for the oil industry,.."

36 Source: Alberta Energy, ***Annual Report***, (1986: p. 11-21).

Table 2.6: The range of oil royalty rates in Saskatchewan and Alberta, 1981-1985 [37]

Year	Saskatchewan (1),(2)&(3)		Alberta (4)	
	New Oil(%)	Old Oil(%)	New Oil(%)	Old Oil(%)
81/82	0-39.62	0-56.6	n/a	n/a
83/84	0-43.07(non-heavy) 0-38.76(heavy)	0-50.6(non-heavy) 0-45.5(heavy)	0-35	0-45
85/86	0-40(non-heavy) 0-32(heavy)	0-57(non-heavy) 0-45(heavy)	0-30	0-40

Table 2.6 presents the range of royalty rates in both provinces. The royalty and tax rates increase as the quantity of production increases. For example: no royalties will be charged to the producers whose monthly productions are less than 10 M^3 per-well. On the contrary, maximum royalty rates will be changed (i,e: 40% for Saskatchewan's new oil-medium light and 30% for Alberta's) to the producers whose monthly productions exceed 150 M^3 per well.

How will the royalties and taxes affect the firms? Royalties and taxes will affect the producers' returns directly, since the change in royalties and taxes rates will change the net returns from the production of crude. The change in royalty rate will result in the change in the net back price, and thus the value of oil in place. Any change will lead to

37

Sources:
(1)Saskatchewan Energy and Mines, ***Annual Report***, 1985/1986, p. 37.
(2)"The Oil Well Income Tax Regulations 1983," ***Saskatchewan Gazette***,v79,1983, p. 16-17.
(3)"The Oil Well Income Tax Regulations 1981," ***Saskatchewan Gazette***,v77,1981, p. 154.
(4)"Important Events of 1985", Alberta Energy, ***Annual Report,*** 1985, p. 6.

changes in economic incentives for the producers.

The change in incentives will change future profit expectations, and thus the level of exploration activities and finding costs. Another indirect effect is the competing tax claims by the divisions of tax revenue of the federal and the provincial governments. Revenues collected from royalties and taxes often create conflicts between provincial and federal governments.[38] Conflicts tend to affect drilling activities and discovery rates because it will cause the exploration activities to be delayed. As introduced in chapter one, the longer it takes to complete a project, the costlier the project will be (the higher the costs).

By regulating royalties and taxes, the Crowns are expected to encourage exploration activities in the oil industry. If the royalty and tax for 'new oil' are lower than the royalty and tax for 'old oil', more efforts on explorations are expected. The government regulations and the costs within the industry can therefore have a causal-effect relationship, such that when the costs are high, it is necessary to reduce taxes to stabilize the prices, or vice-versa. [39]

---

38 For Example: Paus-Jenssen A., "Resource Taxation and the Supreme Court of Canada: The Cigol Case", ***Canadian Public Policy***, vol.5, no.1, 1979, p. 45-58.

39 For example: W.B. Friedenberg, Z.C.Slagorsky, and A.J. Walsh in "***Government Incentives In Canada's Petroleum Industry***," Canadian Energy Research Institute, Calgary, 1980.

2.5 Summary

This chapter has described the background of oil industry in Saskatchewan and Alberta. The discussion of the complex structure of costs and production is unavoidable because the industry has been continuously developed for many decades in Saskatchewan, and for more than a century in Alberta. Both are well established. This discussion is important in order to provide an accurate analysis.

When a producer enters the oil industry, the first activity is to find oil through the discovery process. This process requires three inputs: drilling efforts , geophysic efforts, and land acquisition. Each input requires cost. The total costs of this process is called the total exploration costs. The outputs of this process is new oil discoveries, which is indicated by reserves addition from new discoveries.

There are many definitions of ’reserves’ in the oil industry. In this thesis, the data for new oil discoveries is from the records of primary addition to the initial recoverable reserves (enhanced oil recovery, or EOR, is not included) per discovery year. The data shows that the ratio of reserves addition from new discoveries to total reserves addition is decreasing in Saskatchewan. It does not perform as well as it does in Alberta.

The wellhead prices in both regions resemble the world price level indicating that the crude markets are very competitive. The markets for crude oil in Saskatchewan and Alberta are mainly the North American markets. Historically speaking, the behaviour of price path in the market can be divided into three eras: stable oil price, rising oil price, and volatile oil price. From this fact, it follows that the analysis of costs is important.

Furthermore, the market connections for crude exists at some costs, namely the transportation costs. There are several ways of transporting crude to the market. For the oil industry in Western Canada, the cheapest long-run alternative of transporting crude is pipelines. To remain competitive, to build the pipelines is required. However, the costs of building these pipelines are high. This is when the support from the governments through their policies are important.

In Canada, there are two governments involved: the Crowns, and the Federal government. There are three prominent roles of the governments' involvement in the oil industry: price control, controlling access to reserves, and taxation. Intervening the oil industry, the governments have regularly affect the producers' profit expectations in crude oil exploration activities.

The governments receive revenues from collecting royalties and taxes. The rates of royalties and taxes are determined by the Crowns. Even then, the complex structures of taxation often create debates between the provincial and the federal governments. This will also affect the crude oil exploration activities.

For Saskatchewan and Alberta oil industries, the Crowns policies are effective in regulating the land input, but not the drilling and geophysic inputs because labour and capital are assumed to be very mobile between the two producing provinces.

For the producers, the higher the tax rates, the lesser profits they will receive from the production of oil. Thus, royalties and taxes can effect total revenues directly. Royalties and taxes can also affect the exploration activities indirectly through the expected incentives received by the producers. Historical data shows that Saskatchewan’s royalty and tax rates are always higher than Alberta’s, and this may partially affect the producers behaviour toward crude oil exploration in both regions.

Chapter 3

Literature Review

3.1 The Review

In any form of market analysis, the concept of average and marginal cost is crucial. Finding cost is part of the total cost and will contribute to both average and marginal cost. Therefore, the analysis of finding cost is important for the economic analysis of the oil industry.

In the competitive market the marginal cost reflects the supply of the industry. Hotelling puts it this way:

> This will not apply to monopoly, where the form of the demand function is bound to affect the rate of production, but is characteristic of completely free competition. The various units of minerals are then to be thought of for being at any time all equally valuable, excepting for varying costs of placing them upon the market [40]

Hotelling (1931) explored the study of resource economics in his article "The Economics of Exhaustible Resources". The

---

40 Hotelling, H., "The Economics of Exhaustible Resources," ***Journal of Political Economy***, vol.39, no.2, 1931, p. 140.

essence behind Hotelling’s hypothesis is that the price minus marginal cost of an exhaustible resource is expected to grow exponentially at a rate of interest under ’free competition’. The marginal revenue minus marginal cost should rise at the rate of interest in the monopoly market. Monopoly price will be higher than competitive price, and the difference between the two prices will depend on the level of production cost.

The assumptions behind Hotelling’s model are: that natural resources are irreplaceable; there is some fixed stock of reserves; there is an optimum rate of production; the price is determined from the total costs of extraction and placing it upon the market; the final exhaustion will eventually occur (the quantity of reserve will then becoming zero). This condition will apply to all exhaustible resources because there exist a finite time of ultimate exhaustion.

Hotelling’s analysis provides some answers to the price and costs behaviour over time. He was able to determine the optimal rate of production in the world where stocks of reserves are fixed. He provided solutions for the optimal production path, maximum social value, capital value taxes, and the price behaviour. The analysis was also extended for the case of perfect competition, monopoly, and monopolistic competitions (duopoly). His study became influential in the modern literature of resource economics.

There is however something 'missing' in Hotelling's analysis. For him, the amount of reserves in the ground is fixed. In reality, oil reserves are progressively added through the role of explorations, developments, and technological enhancements. The model fails to recognize the role of exploration and discovery process within the industry. As Adelman states: "There is no fixed stock, only a flow into current inventory, i.e: reserves." [41]

The economic conditions of oil industry worldwide are analyzed by Adelman (1972) in his book "The World Petroleum Market". Adelman's model provides detailed references to the oil industry, including the importance of exploration activities or discovery (finding) process. In an investigation of long run crude supply, he explained the process of exploration, development, production from reserves, and the estimation of costs. The importance of discovery process in terms of cost is clearly indicated in the statement: "To leave discovery cost out of the study would be Hamlet without the prince". [42]

---

41 Adelman, M.A., "Mineral Depletion, With Special Reference to Petroleum," ***Review of Economics and Statistics***, vol. 72, no. 1, 1990, p. 1.

42 Adelman, M.A., "***The World Petroleum Market***," John Hopkins University Press, 1972, p. 6.

The underlying hypothesis behind Adelman's model was the widening cost-price gap in the world oil industry. During the 1970s the price of crude in the world market increased enormously, while the total cost of production in the Middle East was much lower than the total production cost in North America. The condition led to an increasing power of OPEC. He then analyzed the 'real price' of crude oil, that is the price after the result of interplay of demand, supply and the competitive level in the market. He points out that if the oil industry is competitive then a marginal cost analysis is important. Under the competitive equilibrium the marginal cost of production should be equal to the real price of oil.

Adelman's work provides insights for the economic analysis in this thesis. After considering the role of exploration, he writes:

> Exploration is a process of spending money to find oil deposits, and the more barrels found per dollar the lower is the unit finding cost. At any given time there are a number of places to look, and the *better places are preferred*. A concessionaire deciding which area to turn back and which to keep is doing an exercise in *increasing costs*. [43] (emphasis added)

This is important. Finding cost, according to Adelman, is the

43 Ibid, p. 17.

total exploration expenditures over the quantity of oil discoveries. As more oil is discovered, the per-unit finding cost will decline. 'The better places' means the lower cost regions. He expects that the exploration activities will flow from some higher cost regions to the lower cost ones. Because the producers have controls over their choices and preferences, they will choose the most promising area to conduct exploration activities. He also expects that the finding costs in all regions will increase over time. The words that follow suggest that the finding costs in two or more producing regions tend to converge in the long run:

> But at any given time, with exploration plans and commitments to be made according to what is then known, the more exploration, the more must it goes into the less promising places. [44]

The hypotheses in this thesis, as stated in Chapter 1, coincide with Adelman's expectations.

The important role of exploration in production of 'non-renewable' resources (rather than 'exhaustible resources') was further examined by Pindyck (1978) in "The Optimal Exploration and Production of Nonrenewable Resources." An important assumption behind his model is that reserves are

---

44 Ibid, p. 18.

not fixed stocks, [45] but they are rather improved over time as exploration ensues. Pindyck introduced a dynamic analysis of crude oil production under perfect competition and monopoly. He observed the optimal path of production and exploration when the initial reserves are both small and large. He concluded that if the initial reserves are small, the price path of crude will be U-shaped. But, if the initial reserves are large, then the price will be steadily increasing as in Hotelling's model.

Uhler (1979) in "Oil and Gas Finding Cost" introduces a model to estimate finding cost in the province of Alberta. According to Uhler, the previous oil discovery of reserves will affect the future probability of oil discoveries. As cumulative discoveries increase and lead initially to an increase in the discovery rate, this increase in cumulative discoveries will also lead to a decline in future undiscovered reserves at a higher rate. Hence, future discoveries will decline even more. This argument implies that the costs of finding oil will increase at increasing rates. Therefore, like other modern literatures of non-renewable resources, [46] the assumption behind Uhler's model is that crude oil production will eventually cease due to the

45 As noted by Adelman (1967, 1972, 1990).

46 Adelman (1972), and Pyndick (1978).

increasing costs.

For Uhler, the definition of 'finding cost' is the average cost of finding oil. Uhler estimated this cost by specifying the production function of the discovery process. He identifies three inputs: the land acquisitions; drilling activities; geological activities. The outputs are discovery of new oil or gas or both. Uhler also takes into account the effect of future finding probabilities (by cumulative reserves addition) and the effect of output price information in the competitive market.

The discovery processes of oil and gas are similar. Both require the same inputs, thus the same set of data. If the intention is to estimate either oil or gas, some problems with the data will occur. In an attempt to overcome this problem, Uhler adopts the same methodology [47] which was introduced by Eglington (1975). [48] The data was generated in the following steps : First, he divided the category wells intent data (oil, gas, and both intent). Second, he aggregated the 'both wells intent' into oil wells intent category, and he calculated the success rates by dividing oil

47 This method were also used by Eglington and Uffelmann (1983) in the later research.

48 Eglington, P.C., "***The Economics of Industry Petroleum Exploration***," Ph.D. dissertation, UBC, 1975.

wells completions by oil wells intent.[49] Third, the approximation of oil exploratory footage is then calculated by multiplying this success ratio with the total exploratory footage.

Using two stages of estimation, Uhler obtained regression results for the province of Alberta. Once the parameter estimates were obtained, he analyzed the information of the substitution possibilities among the three inputs. For Uhler, drilling and geophysic activities are expected to be substitutes, but geophysic and land inputs are expected to be complements. To support his argument, he presented some empirical results of the elasticities of substitutions. His results support his expectations.

Another approach of estimating finding cost was conducted by Livernois (1988) in "Estimates of Marginal Discovery Costs for Oil and Gas". He specified the total cost function for both oil and gas and assumed that multiple outputs technology is available to circumvent the joint products problem. He explained that the marginal finding costs of oil and gas are observable but the breakdown of these costs are not, therefore some sort of estimation technique is required.

---

[49] Uhler argued that the success ratios will be remarkably similar, with or without inclusion of 'both wells intent' category into the calculation of total oil well intent (Uhler 1979:p. 46).

Livernois used the econometric method of iterative three-stage least squares estimation to avoid the possibility of having inconsistent parameters due to simultaneity problems when the two outputs oil and gas are both on the right-hand side and are all endogenous to the firms. He is aware of the inefficiency of the parameter estimates even though they are consistent. He notes that the use of dummy variables will reduce the autocorrelation problem. The function is then differentiated with respect to the two output variables to get the predicted marginal finding costs. The results are then compared with the shadow price reserves. He concluded that the marginal finding costs are considerably smaller and thus provide poor estimate of the reserve price. This is understandable since the finding cost is only a proportion of total cost in the industry.

Cuddington and Moss (1998) attempted to find an evidence of finding cost reduction due to technological change. They estimated the finding costs for U.S. petroleum industry by using two variants of technological indexes in production function: the technology varieties (TV) model, and the quality ladder (QL) model. The analytical framework in estimating finding costs is partly similar to Uhler’s model, but with a different econometric method. They used the error correction model (ECM) to avoid auto correlation among potential endogenous variables. They find evidence of the impact of technological change on finding cost for US petroleum industry, though whether this evidence is robust enough, is still in question.

3.2 Estimating the Volume of New Discoveries

Adelman, Uhler and others realize the importance of finding activities. They also recognize the peculiar problems associated with estimating the costs. Even though the total cost of exploration can easily be determined by knowing the total expenditures spent for the activities, it is difficult to measure the quantity of new discoveries. Therefore, the estimates of per-unit finding cost face a high level of uncertainty. [50] To estimate the finding cost requires some method of estimating the quantity of new oil reserves.

There are many methods to estimate the reserves and new oil discoveries, for example: geological; mathematical economics; engineering; statistical; and econometric method. Geological methods (Mossop 1997) of estimating reserves is through a knowledge of crude oil that trapped within the sedimentary rocks. Mathematical economics (Hotelling 1931, Pyndick 1978) and engineering methods (Hubbert 1962), are methods of estimation through some functional forms and logical arguments. The statistical (Kaufman 1963, Eckbo, Jacoby, and

---

50

$$FC_{\text{per-unit}} = \frac{TC_{\text{exploration}}}{Y_{\text{discoveries}}}$$

Smith 1978, Smith 1980) and econometric methods (Fisher 1964, Khazzoom 1971, Erickson and Spann 1971, MacAvoy and Pindyck 1973, Epple 1975, Uhler 1979, Livernois 1987, Cuddington and Moss 1998) are estimation methods through the process of collecting complex data, and using it to estimate the relations among variables that are believed to be important.

Each method has its special features and importance in the analysis of discovery process, and they all have contributed significantly to provide public information which is widely available. The estimates of new oil discoveries in this thesis rely on the reported data issued by the governments. It is assumed to be reliable.

3.3 Summary

The review of the literature suggests that the producers will exploit profitable opportunities quickly in facing competition in the market. The price will be determined in the market. The costs will increase due to resource scarcity. Faced with two producing regions, the lower cost region is preferred to the higher cost region. Labour and capital are assumed to be mobile. For the producers, it is important to estimate these costs.

Crude oil exploration activities are vital for the industry. These activities are the first step toward success, or failure, of the producers to create profit in the market. There are expenses involve in this activity, namely the exploration expenditures. These expenditures will become worthwhile investments once large quantity of new discoveries are made. The larger the quantity of new discoveries the lower per-unit exploration (finding) cost, and the greater the economic incentives to the producers.

The literature also describes that to estimate per-unit finding cost is difficult due to the uncertainty problem of discovery process. Thus, it is expected that the estimates of unit finding cost will be highly volatile. Nevertheless, an increasing trend of unit finding cost estimates remains to be seen because of the scarcity [51] problem.

In the following chapter, a model of finding cost will be developed. Even though the model is simple, it is yet very useful because the model makes it possible to estimate finding cost, based on the information which is available.

---

51 The definition of 'scarcity' here is the 'economic scarcity,' in essence of Adelman (1972, 1990), Pindyck (1978),and Uhler (1976, 1979, 1986).

Chapter 4

Estimation and Empirical Results

Based on the background of exploration activities for both provinces provided in Chapter 2 and the review of literature described in Chapter 3, one would expect per-unit finding costs to be highly volatile due to the uncertainty of discovery process. One would also expect these costs to increase at an increasing rate due to resource scarcity problems.

This chapter aims at estimating these costs. Uhler's (1979) model will be used to obtain the empirical results in each provinces. [52] These results will be compared with ex-post (actual) per-unit finding costs for that province. The model also allows one to discuss the partial elasticities of substitutions of inputs based on the parameter estimates from each regression.

---

52 Uhler, R.S., "***Oil and Gas Finding Costs***," Study no.7, Canadian Energy Research Institute, 1979.

4.1 Discovery process

The discovery process of crude oil is viewed as a function of efforts, cumulative reserve addition, and information of output price. Uhler specifies the function of oil discovery as:

$$\mathbf{y} = \phi(\underset{+}{\varepsilon_j}, \underset{-}{\mathbf{a}}, \underset{+}{\mathbf{i}}) \tag{4.1}$$

where: y is oil, gas or both discoveries; ε_j are the usual inputs due to oil exploration: drilling efforts, geophysic efforts, and land acquisitions; a is cumulative reserve addition; and i is information of competitive output price. The positive and negative signs on the right hand side of equation (4.1) indicate the effect of each variable on y. Even though ε_j, a, and i altogether will simultaneously affect the quantity of oil or gas discoveries (y), each variable will capture separate effects on the discovery process. The inputs ε_j are assume to be increasing in new oil discoveries. The cumulative reserve addition captures the depletion effect of oil reserves in finding process. The output price affects the oil discoveries through the expected incentives from conducting oil exploration.

To be able to estimate equation (4.1), the notations that illustrates the separate effects of each category of independent variables must be described more specifically.

The more specific function of finding new oil is done by rewriting equation (4.1) as:

$$\mathbf{y = f(\varepsilon_j, u_1)\ h(a, u_2)\ g(i, u_3)} \qquad \mathbf{(4.2)}$$

To estimate equation (4.2) an explicit form of the equation is needed. The $f(\varepsilon_j, u_1)$ function is formulated explicitly as a translog production form because of the flexibility of this function. To describe the negative relation between cumulative reserve addition and oil discovery, $h(a, u_2)$ is formed as a negative exponential function, or $h(a)=\beta e^{-\zeta a}.u_2$, as the more oil reserves have been discovered the harder it is to find new oil in the ground in an exponential fashion. The function $g(i, u_3)$ is formulated as an exponential function, or $g(i)=i^{\delta}.u_3$, as a higher crude price will lead to more exploration activities, and assumably, this will result in larger quantity of oil discoveries. The notation u_j indicates the error terms. To be able to indicate the parameter estimates of the independent variables, as well as to obtain the estimates of the discovery rates, an explicit function of equation (4.2) is written as:

$$\ell n y = C + \sum_j \alpha_{0j} \ell n \varepsilon_j + \tfrac{1}{2} \sum_j \sum_k \alpha_{jk} \ell n \varepsilon_j \ell n \varepsilon_k - \zeta a + \delta \ell n i + u_j \qquad \mathbf{(4.3)}$$

To be a well-defined production function, equation (4.3) is assumed to be homothetic in inputs (efforts). Given a set of input prices, the function is also assumed to be linearly homogeneous in inputs by imposing parameter restrictions: $\Sigma\alpha_{0j}=1$, $\Sigma\alpha_{jk}=0$, j,k=1,2,3. Symmetry of the matrix of second order derivatives is forced by the following restrictions: $\alpha_{jk}=\alpha_{kj}$, for all j and k. The cumulative reserve addition within each province has been aggregated (thus, only one cumulative reserves in each province). The constant term α_{00} and $\ell n\beta$ are embedded in the intercept, therefore only coefficients $C=\alpha_{00}+\ell n\beta$, α_{0j}, α_{jk}, ζ, and δ will be estimated separately for each province.

Profit-maximizing behaviour in the competitive input markets will ensure that the first derivatives of ℓny with respect to $\ell n\varepsilon_j$ are equal to the proportion of the input shares s_j and the total inputs, written as equation (4.4):

$$\mathbf{s_j(\varepsilon_j) = \partial\ell ny/\partial\ell n\varepsilon_j = \alpha_{oj} + \sum_j \alpha_{jk}\ell n\varepsilon_j} \tag{4.4}$$

There are, however, various measurements of factor inputs such as: meters for drilling, hectares for land, and man-hours for geophysics. The best proxies [53] one can use to estimate these input shares are therefore by the proportion of each expenditure due to input j of the total expenditures. In this thesis, equations (4.3) and (4.4) are estimated with the system of Seemingly Unrelated Regressions (SUR). Applying

---

53 The duality of a production function and a cost function will ensure that the input shares (s_j) should equal the proportion of the expenditures due to j^{th} input of the total expenditures.

twenty five years of data between 1960 and 1985 for each region, [54] the empirical results are presented in Table 4.1.

Table 4.1: Empirical results by using the system of SUR

Alberta			
Coef.	**Est.**	**S.E**	**T-stat**
C	6.085	4.249	1.432
α_{01}	0.543	1.168	0.465
α_{11}	0.155	0.081	1.919
α_{12}	-0.041	0.061	-0.665
α_{13}	-0.112	0.087	-1.297
α_{02}	1.157	0.959	1.206
α_{21}	-0.041	0.061	-0.665
α_{22}	-0.027	0.068	-0.391
α_{23}	-0.008	0.068	-0.121
α_{03}	-0.377	0.756	-0.499
α_{31}	-0.112	0.087	-1.297
α_{32}	-0.008	0.068	-0.121
α_{33}	0.103	0.072	1.429
δ	0.046	0.379	0.121
ζ	8.61E-06	4.13E-06	2.083
Eq.(4.3): R^2=0.417, SE=1.088			
Eq.(4.4,Sdril): R^2=0.280, SE=0.096			
Eq.(4.4,Sgeo): R^2=0.597, SE=0.046			

Saskatchewan			
Coef.	**Est.**	**S.E**	**T-stat**
C	-7.859	1.952	-4.027
α_{01}	-0.154	0.608	-0.254
α_{11}	-0.284	0.421	-0.675
α_{12}	0.076	0.049	1.539
α_{13}	0.037	0.040	0.930
α_{02}	-0.284	0.421	-0.675
α_{21}	0.076	0.049	1.539
α_{22}	-0.065	0.038	-1.725
α_{23}	0.035	0.027	1.288
α_{03}	1.103	0.465	2.372
α_{31}	0.037	0.040	0.930
α_{32}	0.035	0.027	1.288
α_{33}	-0.044	0.033	-1.354
δ	-0.751	0.371	-2.021
ζ	-1.8E-05	8.71E-06	-2.056
Eq.(4.3): R^2=0.454, SE=0.893			
Eq.(4.4,Sdril): R^2=-0.07, SE=0.142			
Eq.(4.4,Sgeo): R^2=0.135, SE=0.073			

54

Raw data is taken from various sources and can be viewed in the appendix of this thesis. Discovery data for Saskatchewan is taken from the ***Saskatchewan Energy and Mines - Reservoir Annual 1999***, and discovery data for Alberta is taken from the ***ERCB - Alberta Reserves 1985***. The quantity of oil discoveries (y) is per-year total cubic meters discovery of initial recoverable reserves of oil (aggregate of all type of crude: heavy, medium, light). The data resulted by adding up all pools data in Alberta and Saskatchewan based on discovery year of the most recent estimates. Drilling efforts (ε_1) is measured by total meters of exploratory drilling each year. The drilling data for both provinces is from ***Statistic Canada***. Geophysical and geological efforts(ε_2) is measured by total man-hours for exploratory wells each year, and the data is taken from ***Statistics Canada***. Land inputs(ε_3) is measured by the total hectares of leases, drilling permits, drilling reservations, gas licenses, gas drilling permits each year. The land data for Saskatchewan is taken from ***Saskatchewan Energy and Mines*** and the land data for Alberta is taken from several sources: ***AERCB***, ***Canadian Petroleum Association***, and ***Alberta Bureau of Statistics***. The share data of input j resulted by dividing the expenditure on input j to total exploration expenditures. The expenditure's data for both provinces is taken from ***Statistics Canada***. Expenditures of each input is adjusted with long-term bond yield for ten industrial interest rates (r) that is taken from ***Bank of Canada***. Cumulative reserves resulted by summing the initial recoverable reserves of crude every year. Price data for Saskatchewan is taken from ***Mineral Statistics Yearbook***, and for Alberta is taken from two sources: ***AERCB Oil and Gas Industry*** and ***Alberta Bureau of Statistics***. The price is the average wellhead price (per-cubic meter) of all type of crude.

The results show that the coefficients of all the inputs for both provinces, except for α_{22}, are of the opposite signs. This is evidence that the structures of oil discoveries in the two regions are very different. Both coefficients ζ and δ are also of the opposite signs, indicating that the market price information and the cumulative reserves addition affect the quantity of crude oil discoveries in both regions differently.

From the model specification, it is quite easy to calculate the partial elasticity of substitutions (ES_{jk}) of the three input categories in each producing region. From the results of the parameter estimates, it can be shown that the partial elasticity of substitutions (ES_{jk}) among the three inputs are: [55]

$$\mathbf{ES_{jk}} = \frac{\alpha_{jk} + s_j s_k}{s_j s_k} \qquad \textbf{(4.5)}$$

Economists are often interested in observing the degree of substitutability among variable inputs for many reasons: from simply curiosity to policy recommendations. Uhler(1979) and Livernois(1987) believe that only drilling and geophysic inputs are substitutes. It is also reasonable to expect that

55 See: Greene, W.H., "Systems of Regression Equations," in ***Econometric Analysis***, Fourth edition, NJ: Prentice Hall, 2000, p. 642.

these inputs to be complements because all the three inputs are required in the process of finding new oil. Nevertheless, the degree of substitutability and complementarity among the three inputs may change over time. Drilling oil is the process with an uncertain outcome. The demand for inputs will depend on the reliability of the information obtained in the past. Cumulative information about an area under exploration changes with the passage of time. When land sale is provided with a reliable geophysical survey in the past, further geophysical activity will not be required. Moreover, the techniques of geological and drilling activities have been continuously developed. Thus, the degree of complementary and substitutability should change over time.

The results of elasticity of substitutions at selected points of observations are presented in Table 4.2.

Table 4.2: Partial elasticity of substitutions for both provinces, selected years

	Alberta			Saskatchewan		
Year	**ES12**	**ES13**	**ES23**	**ES12**	**ES13**	**ES23**
1980	0.54	0.29	0.86	1.71	1.26	1.74
1981	0.5	0.32	0.8	1.89	1.23	1.51
1982	0.42	0.36	0.86	2.06	1.27	1.32
1983	0.28	0.37	0.89	3.01	1.29	1.32
1984	0.46	0.35	0.88	1.92	1.22	1.54
1985	0.59	0.26	0.85	1.69	1.26	1.57

Note: -ES_{12} = Partial elasticity of drilling and geophysics
-ES_{13} = Partial elasticity of drilling and land
-ES_{23} = Partial elasticity of geophysics and land

The table shows that the results do not support the expectation of complementarity described above.

The partial elasticity of substitutions for both regions are positive and relatively stable over time, indicating that all the three inputs are substitutes. [56] The degree of substitutability among the three inputs in Saskatchewan is stronger than it is in Alberta. The information about prospective lands in both regions have been developed well in the 1980s. Consequently, these results suggest that lesser drilling efforts and proportionally more geophysics efforts (or lesser drilling efforts but buying some vaster land areas) will yield the same magnitude of crude oil findings. [57]

4.2 Estimation of New Oil Discoveries

The fitted values of the estimations in Table 4.1 can be interpreted as the log of oil discovery estimates for both regions. [58] The empirical results of the quantity of oil discovery estimates are shown in Figure 4.1.

---

56 These results are consistent with Uhler (1979) and Livernois (1987).

57 The price boom during the early 1980s may be one of the reasons that affect the degree of substitutability among these inputs.

58 Recall Equation (4.3).

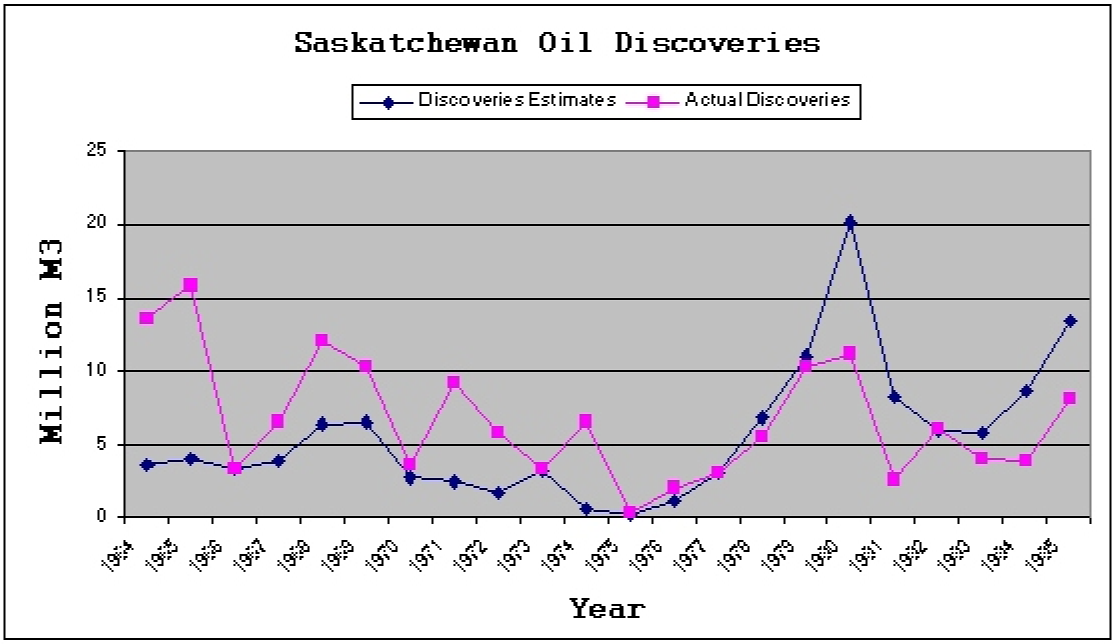

Figure 4.1: Oil discovery estimates - Saskatchewan,1964-1985

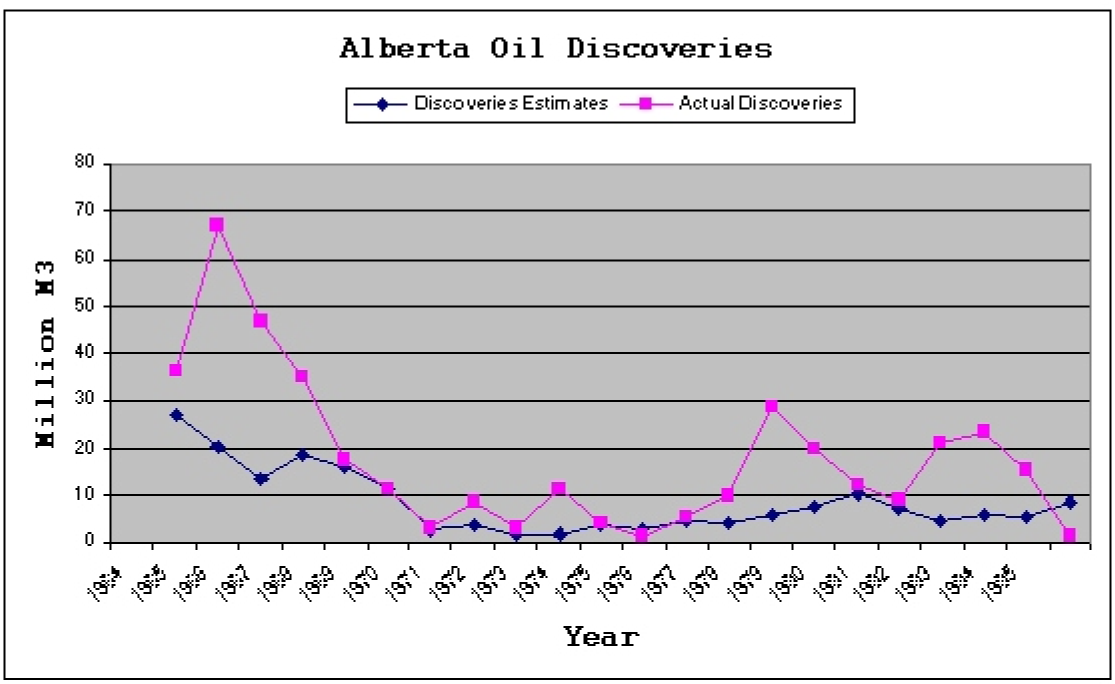

Figure 4.2: Oil discovery estimates - Alberta,1964-1985

The quantity of crude oil discovery estimates in Saskatchewan fit the data quite well. Some overestimation occur only in the 1980s by roughly five million cubic meters on average. Figure 4.2 shows crude oil discovery estimates for Alberta. They also fit the data well even though few are underestimated; in 1979, 1983, 1984, and 1985; by around ten million cubic meters on average.

What are the causes of these over/underestimation? In fact, this underestimation is not surprising at all given that information is imperfect. Estimating the 'real world economy' is very complex. As the consequence, the estimated values are normally different from the actual values.

4.3 Estimation of Finding Cost

Once the discovery rates are estimated, the next task is to estimate the finding costs for both provinces. Per-cubic meter finding cost($/M^3) of new oil discoveries can be calculated by dividing the total exploration expenditures($) to the predicted value of oil discoveries every year(M^3). The total exploration expenditures of 'efforts' consist of the three inputs categories: land, geophysics, and drilling expenditures. As presented in Figure 4.3 and Figure 4.4, the total exploration expenditures in both provinces started to rise after 1975 in response to high activities shortly after the crude price shock in the international market.

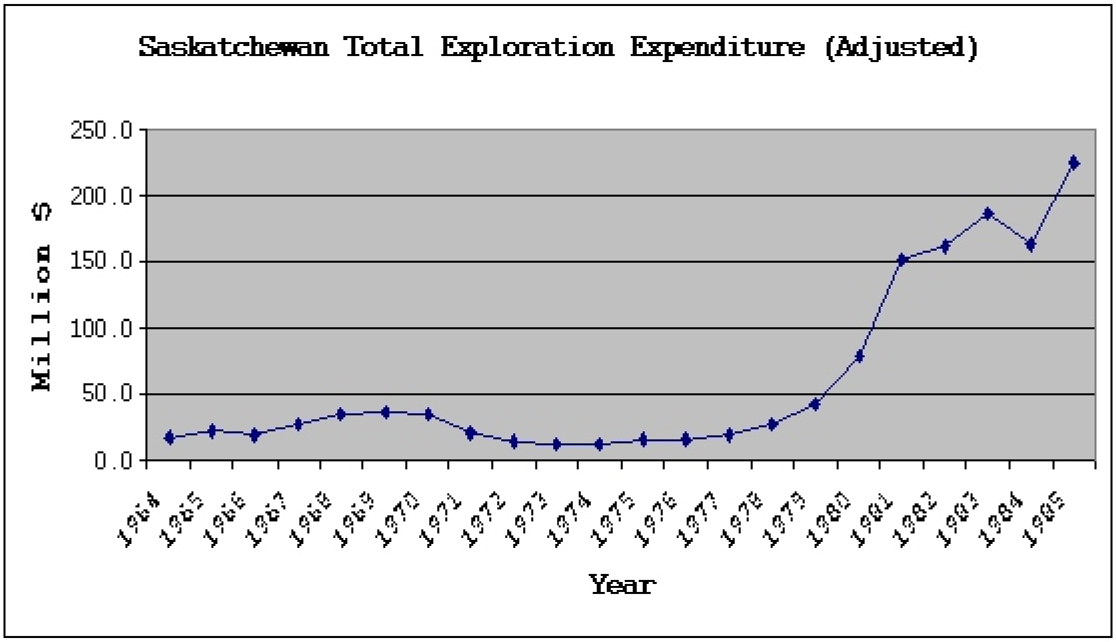

Figure 4.3: Exploration expenditures - Saskatchewan,1964-1985

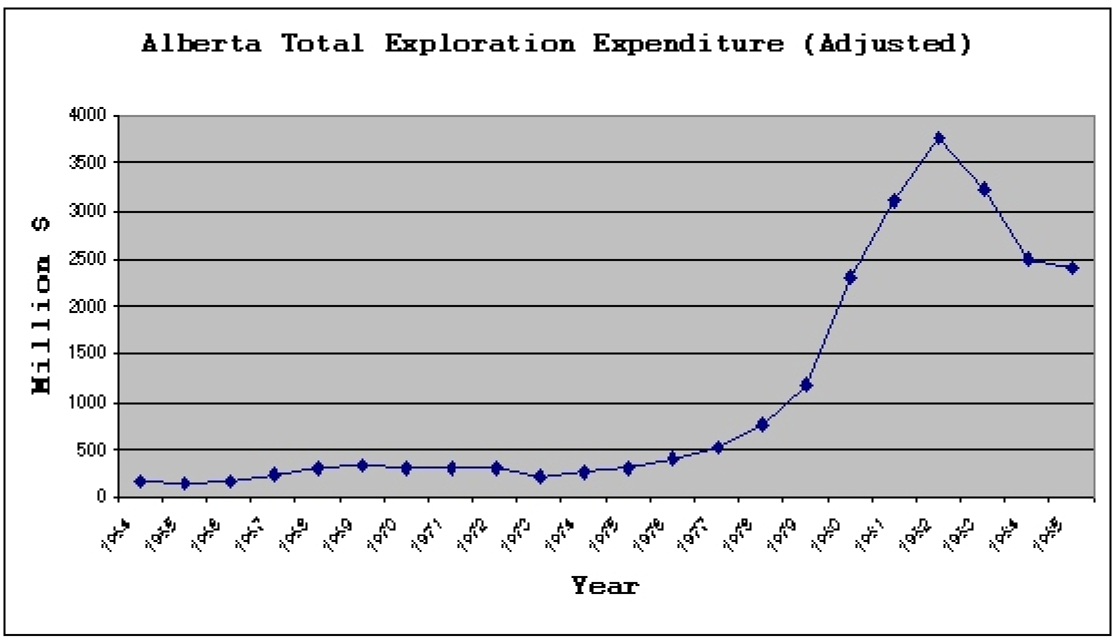

Figure 4.4: Exploration expenditures - Alberta,1964-1985 [59]

---

59 Adjustments to the total expenditures is provided in appendix - Table A1.1 and A1.2.

It is very reasonable to treat the exploration expenditures as investments. When a new exploration activity begins, the money is spent, but there is no guarantee whatsoever that a profitable new oil discovery will be made. The average time lag between land expenditures invested and oil discoveries occurred (if any) is around three years. Two years time lag is assumed for geophysical expenditures, and only one year for drilling expenditures. [60] For example: the expenditures on land will become costs in the next three years, when the exploration result is known. Thus, the expenditures should be compounded by $(1+r)^3$, where r is the interest rate. [61] Similarly, the geophysical expenditures should be compounded by $(1+r)^2$ and the drilling expenditures by (1+r).

The total cost [62] is then the sum of all the expenditures associated with the three categories of inputs, after adjustments to the average time lag and the potential interest forgone were made.

---

60 It is important to note that the money has already been spent for the activities, but the outcomes(new oil discoveries) are uncertain. Thus, there are implicit costs involved, namely the cost of money (potential interest forgone) due to exploration. For example: producers may invest millions of dollars in a financial institution and received compounded interests depending on how long the money is invested. The longer it takes to conduct an activity the costlier the exploration.

61 In this thesis, Bank of Canada 3 to 5 years bond rate is used (see Appendix 1). It is assumed that buying bonds with large sum of money is preferred to any kind of investments because of smaller risk.

62 The adjustments for both regions are tabulated in Appendix 1 (Table A1 and A2).

Once the total cost is yielded, the average finding cost can now be calculated by dividing these adjusted total expenditures by the estimated oil discoveries from the previous section. The results are presented in Table 4.3.

Table 4.3: Finding cost per-unit, estimates and real ex-posts - Saskatchewan and Alberta, 1964-1985

	Saskatchewan					Alberta				
Year	TC (Mil $)	Oil Disc (Mil M^3)	Est. Disc (Mil M^3)	FC Real ($\$/M^3$)	FC Est. ($\$/M^3$)	TC (Mil $)	Oil Disc (Mil M^3)	Est. Disc (Mil M^3)	FC Real ($\$/M^3$)	FC Est. ($\$/M^3$)
1964	16.65	13.53	3.47	1.23	4.79	154.9	36.63	26.99	4.23	5.74
1965	22.88	15.87	3.92	1.44	5.83	143.8	66.98	20.42	2.15	7.04
1966	19.53	3.28	3.23	5.94	6.05	167.9	46.66	13.55	3.60	12.39
1967	26.93	6.51	3.82	4.14	7.05	224.9	34.85	18.33	6.45	12.27
1968	35.00	11.97	6.38	2.92	5.49	298.6	17.68	15.99	16.89	18.67
1969	35.92	10.37	6.48	3.46	5.55	323.6	11.22	11.07	28.86	29.24
1970	35.27	3.49	2.65	10.1	13.33	301.3	3.33	2.63	90.40	114.62
1971	19.85	9.17	2.38	2.16	8.32	304.7	8.34	3.71	36.53	82.07
1972	14.94	5.78	1.71	2.58	8.73	307.3	2.97	1.68	103.44	183.14
1973	13.23	3.28	3.10	4.04	4.27	214.5	11.23	1.97	19.10	109.08
1974	13.10	6.50	0.50	2.02	25.95	250.3	3.85	3.60	64.98	69.61
1975	15.74	0.22	0.15	70.88	105.6	317.6	1.34	2.85	236.27	111.61
1976	15.53	2.01	1.17	7.74	13.28	394.3	5.55	4.32	70.99	91.20
1977	19.57	2.94	2.94	6.66	6.65	524.6	9.91	4.20	52.91	124.98
1978	26.51	5.58	6.79	4.75	3.9	762.3	28.91	5.78	26.37	131.81
1979	42.19	10.31	11.07	4.09	3.81	1,182	19.97	7.49	59.23	157.98
1980	78.86	11.17	20.18	7.06	3.91	2,295	12.18	10.18	188.37	225.48
1981	151.7	2.49	8.16	60.98	18.59	3,102	9.00	7.11	344.62	436.10
1982	160.6	6.06	5.87	26.5	27.36	3,765	21.10	4.49	178.45	838.04
1983	186.8	3.93	5.81	47.57	32.15	3,214	23.56	5.71	136.45	563.25
1984	162.2	3.84	8.64	42.28	18.79	2,482	15.26	5.28	162.73	470.16
1985	225.2	8.07	13.38	27.9	16.83	2,410	1.37	8.64	1,765.	279.05

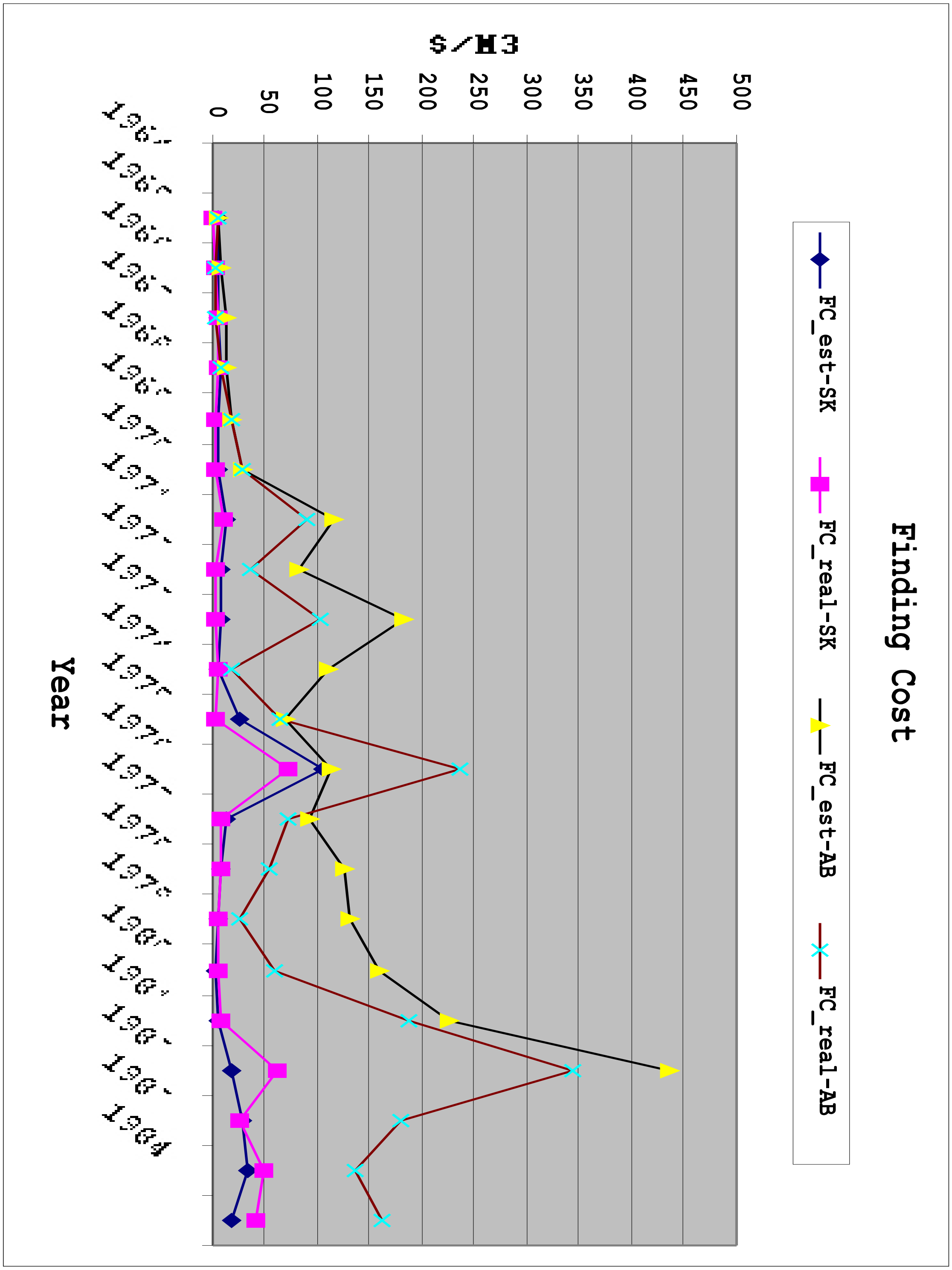

Figure 4.5: Crude Oil FC - Saskatchewan VS Alberta, 1964-1985

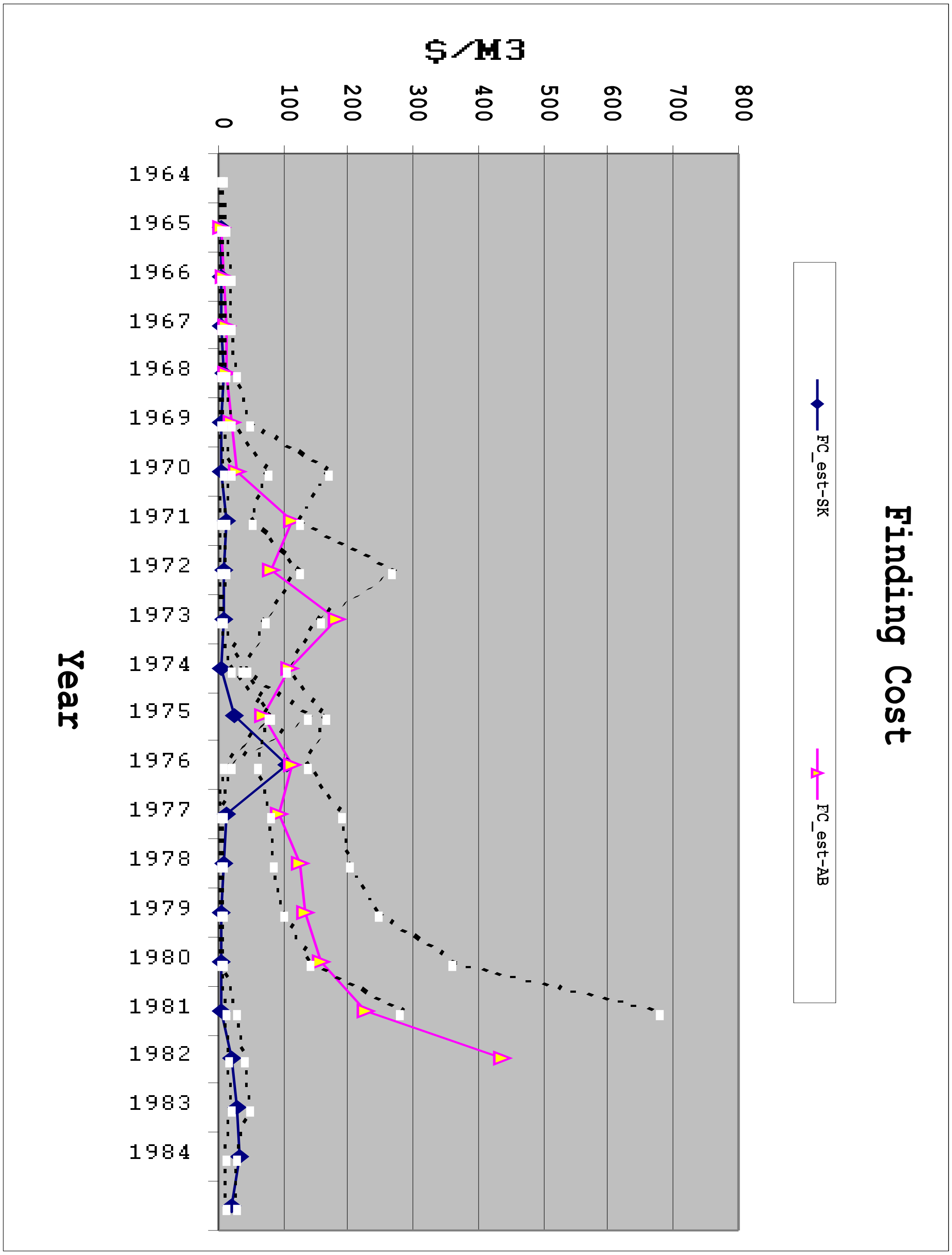

Figure 4.6: FC high vs FC low in 95% confidence interval - both regions, 1964-1985

The limited size of the time series data has caused the results to be less robust than they would have been with a larger sample. The last ten years of discovery estimates are overestimated for Saskatchewan. Actual discoveries [63] made during this period was 5.64 million M^3, but the estimation in Table 4.3 is 8.4 million M^3. While they are overestimated for Saskatchewan, underestimations occur for Alberta. Alberta's actual data [64] of new oil discoveries from 1976 to 1985 was 14.68 million M^3, but the average estimates is only 8.71 million M^3. It is not clear why one set of estimates should differ in this matter from the other set of estimates. Figure 4.6 is therefore depicted at 95% confidence interval in an attempt to show the significance of the finding cost differences are between the two regions.

Nevertheless, Table 4.3 reveals some puzzles about total finding costs and new oil discoveries in the two producing regions. In each province there appears to be three separate periods in terms of the movements of the total finding costs and the oil discoveries.

First, in Alberta between 1964 and 1967, total finding cost was relatively low with large but declining discoveries. From

---

63 Source: Saskatchewan Energy and Mines, ***Reservoir Annual 1999***, Initial Reserves-Primary, p. C-2 - C-21.

64 Source: ***ERCB - Alberta Reserves 1985***, Initial Established Reserves-Primary, p. 2-2 - 2-145.

1968 to 1976 the total cost was higher with declining discoveries. Finally from 1977 onwards, there was a rapid increase in the total finding cost with an increase in discoveries in some years, and small discoveries in other years.

Second, from 1964 to 1970, Saskatchewan’s total finding cost was increasing with some large discoveries in some years, but small discoveries in other years. From 1971 to 1977 the total cost was fairly stable with declining oil discoveries. At last, between 1978 to 1985, the total finding cost increase sharply, with increasing but volatile oil discoveries.

In general, the total finding costs in both regions increased slowly in the 1960s and the early 1970s, but they increased very rapidly in the late 1970s and the 1980s. Some cyclical variations indeed occurred around their secular trends, but they did not vary largely. Even so they were increasing, the magnitude of new oil discoveries in the last period were not as large as its level in the 1960s. By 1976, a trend of increasing finding costs emerged in both regions.

The increasing trends were assumably triggered by the first world oil price shock. But if the price shock is really responsible in the upward trends of the total finding costs, how and through what channels did it affect the costs?

International crude prices had been increasing as a consequence of OPEC output limitations. The Canadian government responded with policies to encourage an expansion in domestic oil supplies. The domestic supply responses encountered the scarcity problem with increasing finding costs.

Alberta's total cost started to rise enormously in 1976. In the course of five years alone (1976-1980), the total cost had increased by 482%, from the total of CAD 394 millions in 1976 to more than CAD 2.29 billions in 1981. The average spending for the next five years (1981-1985) stayed on average of CAD 3 billions per year, while the quantity of oil discoveries did not keep up with the money spent. Actual data from Alberta ERCB indeed showed some large oil discoveries (an average of more than twenty millions M^3 per year) were made for few years; in 1978, 1979, 1982, and 1983; however, these 'large' discoveries must be paid with even larger spending (total cost of explorations). Finding costs per-unit therefore increased during this period.

The total cost for Saskatchewan also increased, but not as much as in Alberta during this period. From 1976 to 1980, it increased by 407%, from CAD 15.53 millions to CAD 78.86 millions. In the next five years (1981-1985), the average spending was only CAD 177.35 millions per-year. The records of the quantity of new oil discoveries in Saskatchewan, however, is 38% of Alberta's discoveries. Thus, the average finding cost per-unit of new oil in Saskatchewan was much smaller than it was in Alberta during this period.

The analysis of the increasing finding costs in Saskatchewan and Alberta since 1976 has revealed another puzzle. Why were the finding cost increases in Saskatchewan so much less than the cost increases in Alberta? By 1985, Saskatchewan's finding cost per-unit was about CAD 200 less per cubic meter of crude. Why were the producers spending so much to find new oil in Alberta, compared with Saskatchewan, when the return on investments on new oil discoveries was clearly better in Saskatchewan?

4.4 Summary

Unit finding costs in both regions were stable during the 1950s and 1960s. There were basically no differences in unit finding costs between the two regions when the quantity of crude oil in the ground was plentiful and cheap (recall Figure 4.5). After 1976, the results show that the trend of unit finding costs in both regions increased at an increasing rate and that they were highly volatile due to the uncertainty of discovery process. These facts are consistent with the hypothesis developed in Chapter 1, and the literature described in Chapter 3.

When the unit finding cost curves started to increase in the 1970s, the cost differences between Saskatchewan and Alberta emerged. There were few years when per-unit finding cost curves moved toward convergence, for examples: in 1978, 1982, and 1983. However, a divergence persisted shortly after those years. The average real finding cost differences between 1964 and 1975 were approximately CAD $40/M^3$. Between 1976 to 1985, the average differences increased to more than CAD $200/M^3$.

It is quite surprising that Saskatchewan's unit finding cost was significantly lower than Alberta's, despite records of lesser quantities of new oil discovered in that province. The gap of per-unit finding cost differences between the two regions started at the end of 1970s, and has been widening ever since.

The next chapter will explore the possible causes of per-unit finding cost differences between the two regions.

Chapter 5

The Causes

Lower finding costs in Saskatchewan (Chapter 4) suggest that exploration activities in Saskatchewan promise higher returns than in Alberta (Chapter 3). Nevertheless, the number of exploration activities in Saskatchewan is considerably smaller than it is in Alberta (Chapter 2). What factors might explain the lower finding cost in Saskatchewan, compared with Alberta, and why have the firms not taken advantage of the cost differentials? To answer these questions let us examine the causes which might be responsible for the finding costs differences during the 1980s.

Exploration activities must be related to the producers' expected payoffs from new discoveries. Well-informed and rational producers will seek to maximize their expected profits. When finding costs differ between two regions, under competitive conditions, the producers are expected to take advantage of the lower finding cost and expand their activities in the low cost region. They will continue to do so until their finding costs have been equalized between the two regions.

There may be three possible reasons why the producers might act on the view that Alberta is a more promising area:

1. The expected magnitude (quantity) of finding new oil.
2. The expected quality of new oil discoveries.
3. The impact of provincial public policies.

All of them will affect the future profit expectations.

5.1 The Expected Quantity of New Oil

The expected quantity of finding oil, or the size of reservoirs, is crucial in decision making because large reservoirs mean large payoffs. The process of finding these reservoirs, however, is risky.

The literature recognizes different types of risks:

1. Geological risk,
2. Commercial risk
3. Political risk

Geological risk reflects the possibility of finding no new oil in place. Commercial risk is the possibility of finding new reservoirs, but the costs of development and production activities are sufficiently high to render the new discoveries non-viable. Political risk is a measure of future actions undertaken by the host government with respect to property rights, leasing rights, and royalties and production taxes which may jeopardize the future economic viability of new discoveries. These risks will influence the firms' assessments of the expected profitability of exploration activities in a given region.

The producers' reactions towards risks will depend heavily on their risk taking or risk avoidance decisions. The framing of decisions of the producers' behaviour involves complex studies of psychology and economics. [65] It is difficult to determine whether the producers will make risky investments or not with regards to the expected size of reservoirs prior to new oil finding. It may depend on several factors and is a matter which has not been pursued in this thesis. Sufficient information is not available to analyze finding activities by firm characteristics that would allow an analysis of risk taking and crude oil explorations.

It is nevertheless a fact that the average size of past reservoirs discovered in Alberta has exceed the average size of reservoirs in Saskatchewan. Consequently, it can be assumed that many producers may have a preference towards exploring in Alberta. Information is not available to measure the strength of this preference.

---

65 See: Altman, M., "***Worker Satisfaction and Economic Performance***," M.E. Sharpe, New York, 2001.

5.2 The Expected Quality of New Oil

There are basically three grades of quality of crude; light, medium, and heavy crude. The historical data presented in Figure 5.1 and 5.2 show that the quality of crude discoveries in Saskatchewan are spread evenly among the three types of crude. More than 90% of the quality of crude discoveries in Alberta consist of high quality light crude. If the producers believe that there is higher probability of finding light crude in Alberta compared with Saskatchewan, the expected incentives of finding oil in Alberta will be stronger. According to the information from Shell Canada, [66] the posted crude price at Edmonton indicates that the average difference between the price of sweet light crude and the price of heavy crude ranges from CAD 40/M^3 to CAD 50/M^3.

Heavy crude can also be converted into medium and light crude at some cost. The conversion cost per-cubic meter of heavy crude into light crude is roughly equal to the price difference between the light crude and the heavy crude. Thus, the discoveries of better quality of crude imply higher revenues to the producers, and therefore greater incentives will be offered. The decision of choosing an exploration area will therefore be influenced by the expectation of finding the best quality of crude.

---

66 Source: Shell Canada Website <http://www.shell.ca/code/prices/oilprices.html>.

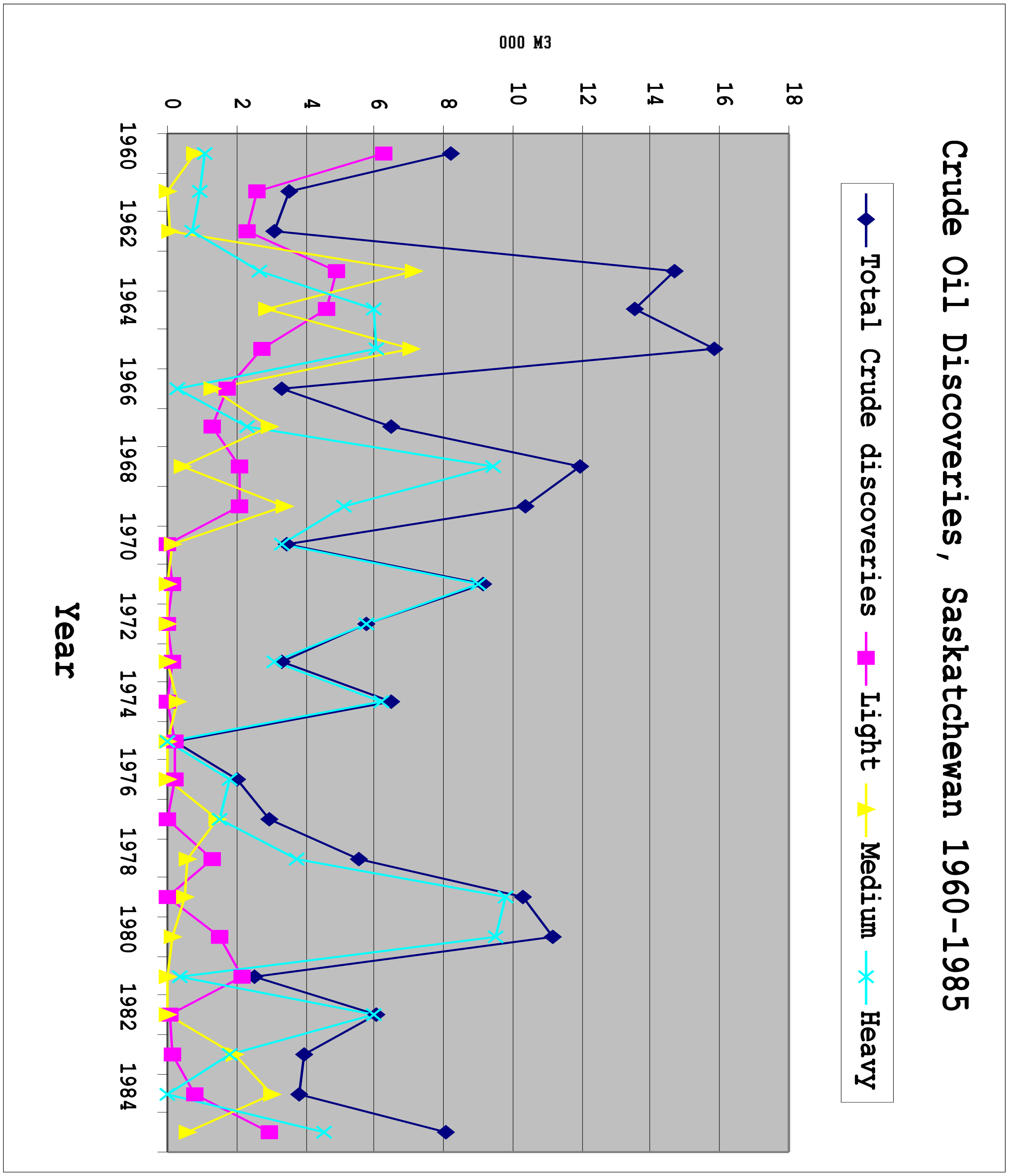

Figure 5.1: The quality and quantity of oil discoveries in Saskatchewan, 1960-1985 [67]

67

Source: Saskatchewan Energy and Mines, ***Reservoir Annual 1999***, Initial Reserves-Primary, p. C-2 - C-21.

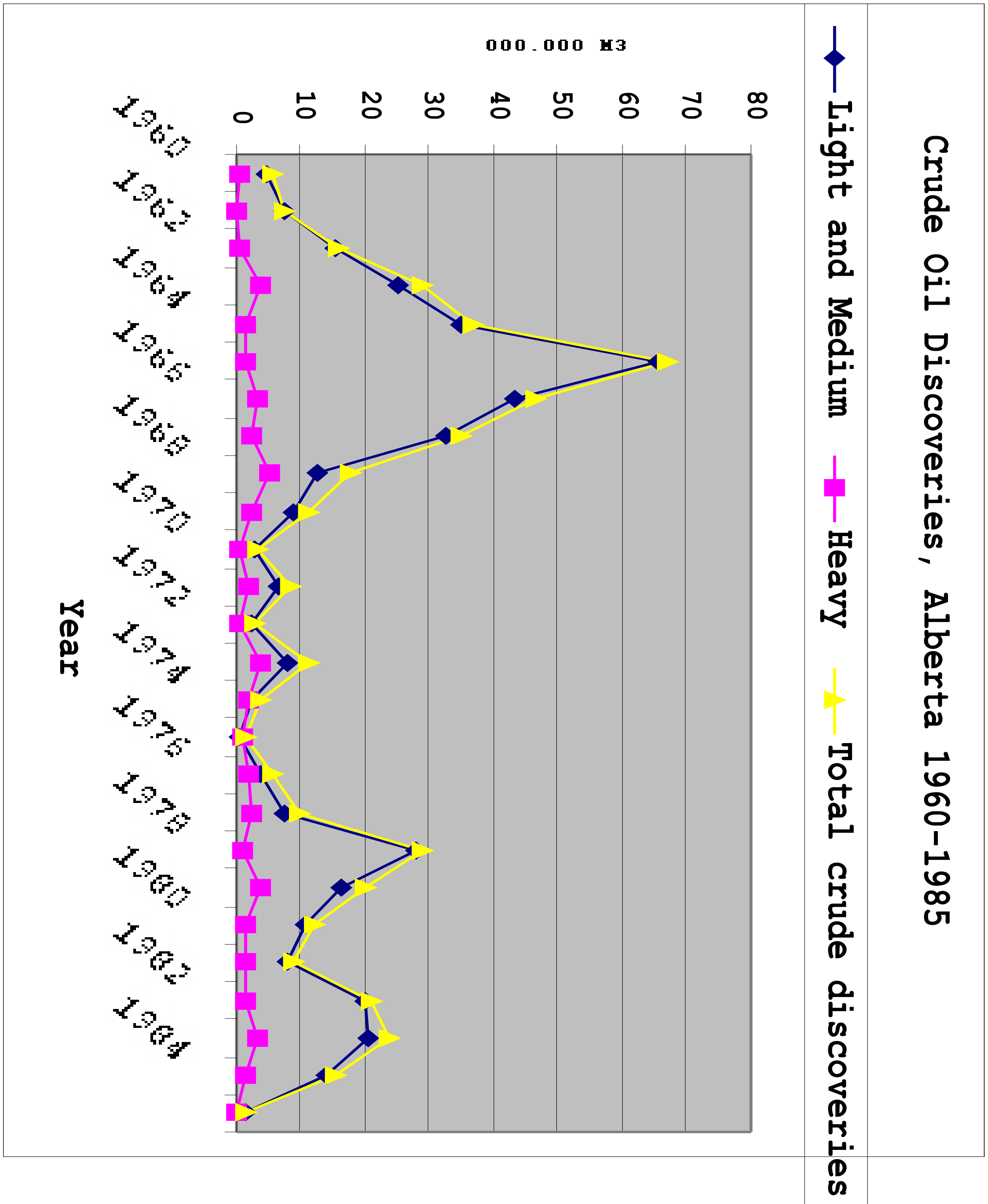

Figure 5.2: The quality and quantity of oil discoveries in Alberta, 1960-1985 [68]

---

68 Source: ***ERCB - Alberta Reserves 1985***, Initial Established Reserves-Primary, p. 2-2 - 2-145.

5.3 Public Policies in the 1980s

The producers' expected profits will also be sensitive to the public policies by the federal or the provincial governments. The provincial government can control the producers expected profits through royalties and taxes, while the federal government can control them through the reference oil prices and taxes. The following sections will examine these policies.

5.3.1 Provincial Oil Taxation

There were significant differences between Alberta and Saskatchewan royalties and production tax rates during the 1980s. The data show that Saskatchewan's royalties were higher than Alberta's by roughly 5% to 37%, depending on the quantity of monthly production. They are tabulated in Table 5.1.

Table 5.1: Royalty rates-Saskatchewan and Alberta, 1985 [69]

Monthly Prod. (M^3)	Royalty & Prod. Tax-New Oil (non-heavy) (%)	
	Saskatchewan	Alberta
<5	0 - 25	0 - 8
50-100	25 - 33	8 - 12
100-150	33 - 36	12 - 18
150-200	36 - 38	18 - 21
200-250	38 - 39	21 - 26
250-300	39 - 40	26 - 29
>300	40	29 - 31

69 Source: Saskatchewan Energy and Mines, ***Annual Report***, 1984/1985, p. 28.

In addition to lower royalty rates, the Government of Alberta offered many advantages to producers who explored for crude during the 1980s. For example, there were tax exemptions, tax rebates, and a five percent Incentives Program (PIP) offered to the producers who explored oil in Alberta. [70] Similar incentives were not offered in Saskatchewan. When these items are included, Alberta producers will enjoy an additional 10% royalty and tax advantage.

5.3.2 Federal Price Control (National Energy Program/NEP)

The federal government together with the provincial governments had created a significant gap between the reference prices of old oil and new oil, and between Canadian prices and international prices in the 1980s. The price difference between old oil and new oil was around CAD 116/M^3 during this period. To produce new oil, one must find it first. For the producers in both regions, the incentives were strong to explore for new oil. The exploration activities in both regions increased enormously in the early 1980s.

5.4 A Restatement of the Finding Cost Differentials

A rough accounting of the producers' expected payoffs from crude oil exploration is presented in Table 5.2. The

---

70 See: ***Alberta Dept. of Energy and Natural Resources,*** *Annual Report*, 1985.

information in the table is taken from various sources throughout this thesis.

Table 5.2: Expected netback to the producers, average monthly production 100 M^3 - Saskatchewan and Alberta, 1985

	Saskatchewan	**Alberta**
Reference Price of 'new oil' (regulated)	**\$ 270/M^3**	**\$ 270/M^3**
Provincial royalty rates for monthly production around 100 M^3 (SK=-33%, AB=-12%)	**(\$ 89.1/M^3)**	**(\$ 32.4/M^3)**
Tax rebate, tax credit, tax incentive (PIP) (SK=0, AB=-10%)	**\$ 0**	**\$ 27/M^3**
Expected quality differences (conversion cost) (SK=heavy oil, AB=light oil)	**(\$ 50/M^3)**	**\$ 0**
Netback Price (after taxes and conversion factor)	**\$ 130.9/M^3**	**\$ 264.6/M^3**

The average crowns' royalties and production tax rates difference are tabulated in Table 5.1. The cost of converting heavy crude to light crude is based on industry estimates.[71] The netback price to the producers is calculated by subtracting the taxes and the conversion costs from the reference price.

The difference in netback prices between Alberta and

71 Source: Shell Canada Website <http://www.shell.ca/code/prices/oilprices.html>.

Saskatchewan is estimated at about CAD 133.7/M^3. This means higher incentives from explorion in Alberta compared with Saskatchewan during this period. The difference in estimated netback prices is significant and goes a long way to explain why finding costs are likely to be lower in Saskatchewan.

We began our analysis of finding costs by assuming competitive market conditions. We assumed that exploration costs in different regions would show a tendency to converge. Different tax structures and rate levels will cause the producers to react. If the reference price is the same for oil produced in different regions but output taxes differ between the two regions, the producers will reduce outputs in the high tax region in an attempt to equalize the net price received from the last unit produced in both regions. The result is that production (finding) costs will therefore differ and the anticipated convergence of finding costs will not occur.

5.5 Summary

It is possible to offer three reasons to explain why the oil discovery costs in Saskatchewan are likely to be lower than in Alberta. First, the quantity of crude oil discoveries in Saskatchewan was smaller than the quantity of oil discoveries in Alberta. Second, most of oil discoveries in Alberta consisted of high quality light crude, which is valued more than heavy crude. Finally, public policies of the two provinces were different in the 1980s. The differences between these policies have created strong incentives to explore in Alberta and discouraged exploration activities in Saskatchewan. And as suggested above, the tax differences are important in explaining the finding cost differences and why Saskatchewan has become a 'lower cost' finding region.

Chapter 6

Conclusion

The analysis of twenty five years of data show that finding costs for both provinces are increasing as expected. The evidence that these costs will tend to converge in the long run is less clear. An important finding is that per-unit finding costs in Saskatchewan is significantly lower than it is in Alberta over time.

The real finding costs per-cubic meter of crude differed by roughly CAD 50/M^3 on average from 1965 to 1979. This result was expected. The producers' willingness to spend more to explore crude oil in Alberta, where oil findings consisted mostly of light crude, mirrors the cost of converting heavy crude into light crude at around CAD 50/M^3. Alberta is therefore expected to have a higher per-unit finding cost compared with Saskatchewan.

The finding cost difference increased to roughly CAD 200 per-cubic meter in the early 1980s. It is largely explained by the different public policies in the two provinces as indicated in the previous chapter. Alberta has continuously served as a low-tax regime, but Saskatchewan has not. Public policies designed to encourage exploration activities clearly attracted many firms to explore in Alberta. To the extent the policies sought to encourage more drilling in Alberta they were successful. To the extent they were designed to discover more oil they were much less successful.

The aggregate consequences of public policies are best illustrated by looking at the total finding costs in Saskatchewan and Alberta between 1976 and 1985. This was the time of very active federal energy policies, and equally active provincial policies. The federal government’s National Energy Program (NEP) was designed to increase the supply of crude oil produced in Canada by offering subsidies and extensive tax incentives.

In Alberta between 1976 and 1985 the total cost of exploration was close to CAD 20 billions. The total quantity of crude oil discoveries (all types) during this period was about 147 million cubic meters. In the same period, the total cost of exploration in Saskatchewan was about CAD 1 billion and discoveries amounted to 56 million cubic meters. Clearly, exploration activities in Saskatchewan offered better returns from 1976 to 1985.

The combination of federal and provincial incentive policies to stimulate exploration appears to have created very expensive ’new oil’ discoveries in Alberta.

The future consequences of these developments and the importance of public policies to shape the ’finding process’ of new oil in Canada are important issues. It is interesting to speculate that the higher taxes and royalties imposed in Saskatchewan may have contributed to a more efficient supply process of new sources of crude in Canada. It is bothersome to observe that billions of dollars were spent in Alberta, encouraged by public policies, searching for new oils and finding little. Is this evidence of policy induced misallocation of resources or is it simply the normal outcome of the process of searching for new oil?

The evidence from this thesis is raising many issues and questions for future research, which were not anticipated when this study was initiated.

Bibliography

1. Adelman, M.A., "Trends in Costs of Finding and Developing Oil and Gas in The US," in ***Essays in Petroleum Economics***, edited by S.H. Hanke and S.L. Gardner, Golden: Colorado School of Mines, 1967, p. 54-91.

2. Adelman, M.A., "***The World Petroleum Market***," John Hopkins University Press, 1972.

3. Adelman, M.A., "Mineral Depletion, With Special Reference to Petroleum," ***Review of Economics and Statistics***, vol. 72, no. 1, 1990, p. 1-10.

4. Alberta Energy, ***Annual Report***, ERCB Review of Alberta Energy Resources - Annual, 1984-1994.

5. Alberta ERCB, ***Reserves of Crude Oil, Gas, Natural Gas Liquids, and Sulphur of Alberta***, 1985.

6. Altman, M., "***Worker Satisfaction and Economic Performance***," M.E. Sharpe, New York, 2001.

7. Angevine, G.E., "***The Impact of a Sharp Oil Price Increase***," Study no.11, Canadian Energy Research Institute, 1980.

8. Bradley, P.G., "***Costs and Supply of Natural Gas from Alberta: An Empirical Analysis***," Discussion Paper no.251, Economic Council of Canada, 1984.

9. Capen, E.C., "The Exploration Decision – How Much Luck? How Much Skill?," in ***Economics of the Explorer***, Edited by R.E. Megill, AAPG Studies in Geology no.19, 1985.

10. Chiang, A., "***Elements of Dynamic Optimization***," McGraw-Hill, Inc., 1992.

11. Conrad, J.M., and C.W. Clark, "Non-Renewable Resources," in ***Natural Resources Economics***, Cambridge University Press, 1987.

12. Cuddington, J.T. and D.L. Moss, "***Technological Change, Depletion and the U.S. Petroleum Industry: A New Approach to Measurement and Estimation***," Georgetown University Working Paper no. 96-10R, 1998.

13. Dasgupta, P.S. and G.M. Heal, "***Economics of Exhaustible Resources***," Cambridge University Press, 1979.

14. Dawson, J.A. and Z.C. Slagorsky, "***Benefits and Costs of Oil Self-sufficiency in Canada***," Study no.12, Canadian Energy Research Institute, 1980.

15. Devarajan, S. and A.C. Fisher, "Exploration and Scarcity," ***Journal of Political Economy***, 1982, vol 90, no.6, p. 1279-1290.

16. Eckbo, P.L., H.D. Jacoby, and J.L. Smith, "Oil Supply Forecasting: A Disaggregated Process Approach," ***Bell Journal of Economics***, vol.9, no.1, 1978, p. 218-235.

17. Eglington, P.C., "***The Economics of Industry Petroleum Exploration***," Ph.D. dissertation, UBC, 1975.

18. Eglington, P.C. and M. Uffelmann, "***Observed Costs of Oil and Gas Reserves in Alberta, 1957-1979***," Discussion Paper no.235, Economic Council of Canada, 1983.

19. Epple, D.N., "***Petroleum Discoveries and Government Policy: An Econometric Study of Supply***," Cambridge, MA: Ballinger, 1975.

20. Erickson, E.W. and R.M. Spann, "Supply Price in a Regulated Industry: The Case of Natural Gas," ***Bell Journal of Economics and Management Science***, vol. 2, no.2, 1971, p. 94-121.

21. Fisher, F.M., "***Supply and Costs in the US Petroleum Industry: Two Economic Studies,***" John Hopkins University Press, 1964.

22. Friedenberg, W.B., Z.C. Slagorsky, and A.J. Walsh, "***Government Incentives In Canada's Petroleum Industry***," Working Paper 80-1, Canadian Energy Research Institute, 1980.

23. Greene, W.H., "Systems of Regression Equations," in ***Econometric Analysis***, Fourth edition, Prentice Hall, 2000.

24. Harkness, J., "Optimal Oil Pricing in a Small Open Economy: a Macro-Economic Perspective," ***Canadian Journal of Economics***, vol.17, no.4, 1984, p. 763-773.

25. Heal, G., "The Relationship Between Price and Extraction Cost for a Resource with a Backstop Technology," ***Bell Journal of Economics***, vol.7, no.2, 1976, p. 371-378.

26. Helliwell, J.F., M.E. MacGregor, R.N. McRae, and A. Plourde, "***Oil and Gas in Canada: The Effects of Domestic Policies and World Events***," Toronto: Canadian Tax Foundation, 1989.

27. Helliwell, J.F., and R.N. McRae, "Resolving the Energy Conflict: From the National Energy Program to the Energy Agreements," ***Canadian Public Policy***, vol.8, no.1, 1981a.

28. Hotelling, H., "The Economics of Exhaustible Resources," ***Journal of Political Economy***, vol.39, no.2, 1931, p. 137-175.

29. Hubbert, M.K., "***Energy Resources***," Washington: National Academy of Sciences - National Research Council, 1962.

30. Khazzoom, J.D., "The F.P.C. Staff's Econometric Model of Natural Gas Supply in the United States," ***Bell Journal of Economics and Management Science***, vol.2, no.1, 1971, p. 51-93.

31. Kaufman, G.M., "***Statistical Decisions and Related Techniques in Oil and Gas Exploration***," NJ: Prentice Hall, 1963.

32. Kuuskraa, V.A., F. Morra Jr., and H.W. Hochheiser, "Replacement Costs of Domestic Crude Oil," in ***Economics of the Explorer***, edited by R.E. Megill, AAPG Studies in Geology no.19, 1985.

33. Krutilla J.V., and A.C. Fisher, "***The Economics of Natural Environments***," John Hopkins University Press, 1975.

34. Leonard, D. and N.V. Long, "***Optimal Control Theory and Static Optimization in Economics***," Cambridge University Press, 1992.

35. Livernois, J.R., "Estimates of Marginal Finding Costs for Oil and Gas," ***Canadian Journal of Economics*** vol.21, no.2, 1988, p. 379-393.

36. Livernois, J.R. and R.S. Uhler, "Extraction Costs and the Economics of Nonrenewable Resources," ***Journal of Political Economy***, vol 95, 1987, p.195-203.

37. Livernois, J.R. and D.L. Ryan, "Testing for Non-jointness in Oil and Gas Exploration: A Variable Profit Function Approach," ***International Economic Review***, 1987.

38. Lovejoy, W.F., "U.S. Oil Import Controls and Incentives," in ***Essays in Petroleum Economics***, edited by S.H. Hanke and S.L. Gardner, Golden: Colorado School of Mines, 1967, p. 54-91.

39. MacAvoy, P.W. and R.S. Pindyck, "Alternative Regulatory Policies for Dealing With the Natural Gas Shortage," ***Bell Journal of Economics and Management Science***, vol.4, no.2, 1973, p.454-498.

40. Megill, R.E, "Exploration – Is the Past the Key to the Future?," in ***Economics of the Explorer***, Edited by R.E. Megill, AAPG Studies in Geology no.19, 1985.

41. Minister of Supply and Services Canada, ***Canada Year Book 1985***, Catalogue No. 11-402E/1985, The Bryant Press Limited, Ottawa, 1985.

42. Mossop G.D., ***Geological Survey of Canada***, Calgary, <http://www.ags.gov.ab.ca/ags_pub/atlas_www/atlas.htm>

43. Paus-Jenssen, A. "Resource Taxation and the Supreme Court of Canada: The Cigol Case," ***Canadian Public Policy***, vol.5, no.1, 1975, p.45-58.

44. Pindyck, R.S., "The Regulatory Implications of Three Alternative Econometric Supply Models of Natural Gas," ***Bell Journal of Economics***, vol.5, no.2, 1974, p. 633-645.

45. Pindyck, R.S., "The Optimal Exploration and Production of Nonrenewable Resources," ***Journal of Political Economy***, vol.86, no.5, 1978, p. 841-861.

46. Porter, R. and K. Hendricks, "Determinants of the Timing and Incidence of Exploratory Drilling on Offshore Wildcat Tracts," ***American Economic Review***, vol.86, 1996, p. 388-407.

47. Saskatchewan Energy and Mines, ***Mineral Statistics Yearbook-Reservoir Annual***, ISSN-0707-2570, 1999.

48. Scarfe, B.L. and E. Rilkoff, "***Financing Oil and Gad Exploration and Development Activity***," Discussion Paper no.274, Economic Council of Canada, 1984.

49. Shojai, S. and B.S. Katz, "***The Oil Market In the 1980s, A Decade of Decline***," Praeger Publishers, 1992.

50. Smith, A., "***An Inquiry into the Nature and Causes of the Wealth of Nations***," New York: Modern Library, 1937.

51. Smith, J.L., "A Probabilistic Model of Oil Discovery," ***Review of Economics and Statistics***, vol.62, no.4, 1980, p. 587-594.

52. Solow, R.M., "The Economics of Resources or Resources of Economics," ***American Economic Review***, vol.64, no.2, 1974, p.1-14.

53. Saskatchewan Energy and Mines, ***Annual Report***, 1972-2001.

54. Statistic Canada, ***Drilling Completions***, catalogue 26-213-XPB,1951-1999.

55. Statistic Canada, ***Energy Statistic Handbook***, Natural Resources Canada CD Rom - May 2001.

56. Takayama, A., "Development of Optimal Control Theory and Its Applications," in ***Mathematical Economics***, The Dryden Press, 1974, p. 600-703.

57. Tanner, J.A., "***An Evaluation of Crude Oil Supply In Saskatchewan***," Study no.25, Canadian Energy Research Institute, 1987.

58. Thaler, R.H., "***The Winner's Curse - Paradoxes and Anomalies of Economic Life***," NY: The Free Press, Macmillan, 1992.

59. Toman M.A. and M. Walls, "Nonrenewable Resource Supply: Theory and Practice," in ***Handbook of Environmental Economics***, Edited by Bromley D.W., Blackwell, 1995.

60. Uhler, R.S., "Costs and Supply in Petroleum Exploration: The Case of Alberta," ***Canadian Journal of Economics***, vol 9, no.1, 1976, pp. 72-90.

61. Uhler, R.S., "***Oil and Gas Finding Costs***," Study no.7, Canadian Energy Research Institute, 1979.

62. Uhler, R.S., "The Supply of Natural Gas Reserves in Alberta," in ***Progress in Natural Resource Economics,*** Edited by: A. Scott, Oxford, Clarendon, 1985.

63. Uhler, R.S.(with P.C. Eglington), "***Potential Supply of Crude Oil and Natural Gas Reserves in the Alberta Basin***," Catalogue no. EC 22-128, Economic Council of Canada, 1986.

64. Watkins, G.C. , M.A. Adelman, E.R. Berndt, P.G. Bradley, P.E. Greenberg, A. Plourde, B.L. Scarfe, L. Waverman, A.W. Wright, "***Petro Markets: Probing the Economics of Continental Energy***," edited by G.C. Watkins, The Fraser Institute, 1989.

65. Wyant, F.R., "***The United States, OPEC, and Multinational Oil***," Mass: Lexington Books, 1977.

Appendix

Data

Table A1.1: Total exploration cost - Saskatchewan

Year	Drilling ($ a	Geo ($ b	Land ($ c	Bond Rate (r)	Interest forgone (1+r)	(1+r)^	(1+r)^	Total Costs, adjusted and lagged Drill(1+ ($	Geo(1+r)^2 ($ Thou.)	Land(1+r)^3 ($ Thou.)	TOTAL ($ Thou.)
1961	4858	2942	1330	0.04	1.04	1.09	1.14	0.0	0.0	0.0	0.0
1962	6503	3597	3767	0.05	1.05	1.09	1.14	5070.5	0.0	0.0	0.0
1963	10717	3783	5378	0.04	1.04	1.09	1.14	6802.1	3205.1	0.0	0.0
1964	13792	2508	8381	0.05	1.05	1.10	1.15	11197.1	3935.5	1512.3	16645.0
1965	10147	6382	11608	0.05	1.05	1.10	1.15	14443.1	4129.5	4311.1	22883.8
1966	9738	6376	7242	0.06	1.06	1.11	1.18	10644.1	2750.4	6133.7	19528.2
1967	13728	11921	9586	0.06	1.06	1.12	1.18	10278.3	7022.6	9624.9	26925.8
1968	13222	11196	5546	0.07	1.07	1.14	1.21	14502.3	7103.2	13399.0	35004.4
1969	10431	6004	5031	0.08	1.08	1.16	1.25	14104.9	13303.6	8515.5	35924.1
1970	5751	2904	4038	0.07	1.07	1.15	1.23	11230.4	12741.1	11301.1	35272.7
1971	5048	2545	2522	0.06	1.06	1.11	1.18	6159.6	6959.5	6732.8	19851.9
1972	5112	3182	5550	0.06	1.06	1.13	1.20	5328.4	3331.3	6278.5	14938.3
1973	6111	2494	5691	0.07	1.07	1.14	1.22	5431.8	2835.6	4961.3	13228.7
1974	5755	989	4486	0.08	1.08	1.17	1.26	6537.8	3592.6	2966.1	13096.5
1975	6875	2920	2353	0.08	1.08	1.16	1.25	6222.5	2854.5	6658.3	15735.3
1976	9698	3517	10684	0.08	1.08	1.17	1.27	7405.7	1156.2	6968.6	15530.5
1977	18017	5691	15486	0.08	1.08	1.16	1.26	10507.8	3388.2	5670.5	19566.4
1978	20160	12570	42751	0.09	1.09	1.19	1.29	19440.8	4128.9	2941.0	26510.7
1979	40274	23196	53919	0.10	1.10	1.22	1.35	21974.2	6626.0	13590.0	42190.3
1980	60589	31034	79925	0.12	1.12	1.26	1.42	44470.2	14934.2	19455.1	78859.5
1981	42264	25406	38011	0.16	1.16	1.34	1.55	68084.4	28281.5	55362.5	151728.4
1982	34606	22294	42656	0.14	1.14	1.30	1.48	48889.2	39187.3	72589.7	160666.2
1983	67329	40602	117245	0.11	1.11	1.22	1.35	39451.1	33995.5	113407.9	186854.6
1984	100370	41874	132540	0.12	1.12	1.25	1.40	74474.3	28973.7	58835.2	162283.2
1985	130711	71838	155909	0.10	1.10	1.22	1.35	112321.6	49677.1	63198.1	225196.7
1986	53255	34873	26757	0.09	1.09	1.19	1.30	144286.4	52440.0	158674.4	355400.9
1987	50472	36802	67853	0.09	1.09	1.20	1.31	58161.6	87534.8	185748.2	331444.6
1988	86056	38065	46563	0.10	1.10	1.20	1.32	55224.4	41595.0	209706.2	306525.5
1989	43019	29650	55038	0.10	1.10	1.21	1.34	94465.1	44058.7	34854.9	173378.8
1990	57236	35089	52828	0.11	1.11	1.24	1.37	47408.4	45867.6	88881.1	182157.1
1991	40627	26485	34477	0.09	1.09	1.19	1.30	63642.1	36009.3	61590.2	161241.6
1992	28421	18087	25294	0.07	1.07	1.15	1.24	44349.4	43383.2	73662.6	161395.3
1993	77811	46838	111838	0.06	1.06	1.13	1.21	30533.2	31560.7	72625.8	134719.6
1994	114139	60033	232586	0.08	1.08	1.16	1.25	82836.3	20875.2	44848.7	148560.2
1995	113109	78257	97459	0.08	1.08	1.16	1.25	123026.6	53083.3	31362.8	207472.7
1996	152793	124611	167441	0.06	1.06	1.13	1.20	121748.6	69746.1	134936.2	326430.9
1997	319615	137205	198316	0.05	1.05	1.11	1.17	162287.8	90668.6	291258.6	544215.0
1998	139686	84732	74214	0.05	1.05	1.11	1.16	336650.5	140579.3	121541.0	598770.8
1999	120960	59750	63213	0.06	1.06	1.11	1.17	146897.3	152220.8	200636.1	499754.3
								127613.8	93706.4	231746.9	
									66504.3	86311.5	
										74229.1	

Source: Various (see page 46).

Table A1.2: Total exploration cost - Alberta

Year	Drillin g	Geo	Land	Bond Rate	Interest forgone			Total Costs and interest forgone			
	($ a	($ b	($ c	(r)	(1+r)	(1+r)^2	(1+r)^	Drill(1+r) ($ Thou.)	Geo(1+r) ($	Land(1+r)^ ($ Thou.)	TOTAL ($
1961	60190	35310	44868	0.04	1.04	1.09	1.14	0.0	0.0	0.0	0
1962	55041	38460	33245	0.05	1.05	1.09	1.14	62823.3	0.0	0.0	0
1963	59188	33010	46930	0.04	1.04	1.09	1.14	57572.9	38467.2	0.0	0
1964	66600	37400	85653	0.05	1.05	1.10	1.15	61839.6	42079.7	51018.3	154938
1965	70004	42091	122027	0.05	1.05	1.10	1.15	69744.1	36033.9	38047.1	143825
1966	76041	68166	101140	0.06	1.06	1.11	1.18	73433.6	41014.5	53524.2	167972
1967	77433	99734	89546	0.06	1.06	1.12	1.18	80260.0	46316.2	98365.3	224942
1968	87613	87150	94614	0.07	1.07	1.14	1.21	81800.2	75940.0	140854.9	298595
1969	89745	86402	104068	0.08	1.08	1.16	1.25	93463.4	111301.2	118926.1	323691
1970	83799	80344	26870	0.07	1.07	1.15	1.23	96622.5	99177.5	105567.8	301368
1971	80793	65528	25031	0.06	1.06	1.11	1.18	89752.9	100152.0	114861.3	304766
1972	102130	71162	65341	0.06	1.06	1.13	1.20	85281.1	92166.5	129873.5	307321
1973	131361	70663	83612	0.07	1.07	1.14	1.22	108519.9	73010.4	33013.9	214544
1974	146474	112396	104313	0.08	1.08	1.17	1.26	140535.5	80345.3	29438.4	250319
1975	149077	99025	132468	0.08	1.08	1.16	1.25	158372.6	80878.1	78388.9	317640
1976	256452	145538	172898	0.08	1.08	1.17	1.27	160584.5	131398.3	102382.8	394366
1977	394679	223412	592681	0.08	1.08	1.16	1.26	277865.7	114902.9	131855.0	524624
1978	644532	350321	659098	0.09	1.09	1.19	1.29	425868.5	170857.6	165573.2	762299
1979	1027537	349690	1046133	0.10	1.10	1.22	1.35	702534.5	260117.5	219926.1	1182578
1980	1621585	452331	1068648	0.12	1.12	1.26	1.42	1134597.8	416210.0	744587.1	2295395
1981	1543732	352254	604108	0.16	1.16	1.34	1.55	1822188.6	426355.8	853531.4	3102076
1982	1076345	325107	465644	0.14	1.14	1.30	1.48	1785724.9	571167.6	1408381.5	3765274
1983	1017395	372740	565099	0.11	1.11	1.22	1.35	1227042.3	471347.5	1516336.1	3214726
1984	1130290	472308	790179	0.12	1.12	1.25	1.40	1125366.0	422515.2	935066.5	2482948
1985	1368317	480546	1021136	0.10	1.10	1.22	1.35	1264879.3	456052.1	689887.2	2410819
1986	1021280	448875	447332	0.09	1.09	1.19	1.30	1510428.1	591484.9	764781.1	2866694
1987	1010772	420040	841141	0.09	1.09	1.20	1.31	1115373.9	585546.8	1107396.3	2808317
1988	1089410	520907	676536	0.10	1.10	1.20	1.32	1105944.6	535398.0	1373484.0	3014827
1989	837997	428531	551664	0.10	1.10	1.21	1.34	1195863.5	502864.5	582716.0	2281444
1990	950172	452026	614152	0.11	1.11	1.24	1.37	923500.6	627683.5	1101816.6	2653001
1991	852031	395387	457122	0.09	1.09	1.19	1.30	1056520.0	520441.2	894873.6	2471835
1992	574808	329692	344868	0.07	1.07	1.15	1.24	930098.3	558874.6	738344.1	2227317
1993	883118	434420	640734	0.06	1.06	1.13	1.21	617525.8	471161.0	844310.8	1932998
1994	1449774	678970	1217700	0.08	1.08	1.16	1.25	940152.7	380516.1	594637.8	1915307
1995	1492415	559959	857166	0.08	1.08	1.16	1.25	1562663.1	492344.6	427612.0	2482620
1996	1546916	574313	1050872	0.06	1.06	1.13	1.20	1606410.6	788825.0	773066.3	3168302
1997	1765824	766982	1322719	0.05	1.05	1.11	1.17	1643043.9	648769.1	1524879.2	3816692
1998	2471505	610350	820842	0.05	1.05	1.11	1.16	1859942.4	647908.3	1068970.8	3576822
1999	1698970	590862	143520	0.06	1.06	1.11	1.17	2599096.4	850921.2	1259207.1	4709225
								1792427.5	674995.3	1545695.2	
									657654.6	954645.8	
										168531.1	

Source: Various (see page 46).

Table A1.3: Government of Canada marketable bonds - average yields, three to five years (%)

Year	Jan	Feb	Mar	Apr	Mei	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
1961	4.6	4.42	4.66	4.73	4.78	4.52	4.4	4.25	4.26	3.97	3.89	4.02	4.38
1962	4.14	4.07	4.01	3.89	4.32	5.5	5.41	5.4	5.21	4.5	4.36	4.39	4.60
1963	4.43	4.51	4.61	4.54	4.32	4.18	4.45	4.6	4.54	4.45	4.55	4.58	4.48
1964	4.64	4.57	4.74	4.81	4.71	4.66	4.74	4.8	4.79	4.77	4.79	4.63	4.72
1965	4.53	4.66	4.62	4.58	4.64	4.87	5.05	5.18	5.09	5.12	5.22	5.23	4.90
1966	5.24	5.38	5.37	5.39	5.37	5.39	5.55	6.09	5.76	5.69	5.77	5.58	5.55
1967	5.2	5.16	4.76	4.81	5.4	5.68	5.89	5.98	6.1	6.05	6.17	6.48	5.64
1968	6.53	6.77	7.12	6.87	7.08	6.79	6.44	6.21	6.25	6.48	6.53	7.06	6.68
1969	6.99	7.03	7.27	7.33	7.69	7.62	7.64	7.71	8.06	8.02	8.31	8.29	7.66
1970	8.23	8	7.32	7.35	7.38	7.07	6.96	7.21	7.12	7.08	6.12	5.42	7.11
1971	5.37	5.54	5.19	5.52	5.86	6.02	6.46	6	5.63	5.04	4.94	5.09	5.56
1972	5.46	5.84	6.29	6.43	6.53	6.68	6.59	6.71	6.57	6.21	5.77	6	6.26
1973	6.25	6.3	6.5	6.67	7.4	7.19	7.39	7.54	7.25	7.09	6.98	7.25	6.98
1974	6.99	6.76	7.57	8.56	8.74	9.24	9.27	9.38	8.89	7.8	7.32	6.96	8.12
1975	6.4	6.38	6.8	7.55	7.31	7.53	8.1	8.36	8.85	8.3	8.64	8.41	7.72
1976	8.21	8.38	8.53	8.46	8.35	8.5	8.55	8.43	8.49	8.44	8.15	7.71	8.35
1977	7.74	7.68	7.85	8.01	7.74	7.76	7.81	7.9	8.01	8.12	8.11	8.1	7.90
1978	8.36	8.46	8.69	8.82	8.85	8.86	8.86	8.86	8.96	9.51	9.84	9.92	9.00
1979	9.88	10	9.89	9.52	9.65	9.73	9.92	10.5	10.9	11.8	11.6	11.7	10.42
1980	12.5	13.2	13.9	11.8	10.9	10.5	11.5	12.3	13	13.2	13.2	12.6	12.37
1981	13.1	13.6	14	15.5	15.6	15.8	18	17.8	18.8	17.1	13.8	15.2	15.68
1982	16.1	15	15.1	14.9	14.9	16.2	15.8	13.6	12.9	11.9	11.2	10.6	14.00
1983	10.8	10.5	10.5	10.2	10.2	10.4	10.8	11.3	10.7	10.6	10.6	10.8	10.61
1984	10.7	11.3	11.9	12.2	13.2	13	13	12.3	12.1	11.5	11	10.8	11.91
1985	10.5	11.6	11.4	10.9	10.2	10.4	10.4	10.2	10.3	9.88	9.56	9.33	10.39
1986	9.95	9.71	9.3	8.96	9.2	9.06	9.19	9.09	9.23	9.18	8.88	8.81	9.21
1987	8.2	8.24	7.97	9.35	9.41	9.27	9.89	10.1	10.9	9.79	10	9.95	9.42
1988	9.23	9.03	9.31	9.56	9.61	9.63	9.92	10.4	10.1	9.78	10.3	10.4	9.77
1989	10.3	10.8	11	10.5	10.1	9.67	9.59	9.9	10.2	9.88	10.4	10.2	10.20
1990	10.3	11.5	11.7	12.4	11.7	11.4	11.3	10.8	11.4	11	10.5	10.5	11.19
1991	10.1	9.57	9.56	9.51	9.38	9.77	9.65	9.39	8.84	8.06	8.19	7.95	9.16
1992	7.9	7.94	8.48	8.32	7.8	7.32	6.36	6.3	7.3	6.71	7.4	7.35	7.43
1993	7.46	7.02	6.96	6.98	6.85	6.52	6.22	6.02	6.27	5.87	5.86	5.47	6.46
1994	5.09	5.81	7.37	7.28	7.95	8.75	8.8	8.18	8.2	8.37	8.64	9	7.79
1995	9.15	8.44	8.25	7.92	7.39	7.22	7.7	7.49	7.47	7.47	6.65	6.51	7.64
1996	6.12	6.66	6.89	6.92	6.84	6.88	6.69	6.32	5.99	5.29	4.77	5.2	6.21
1997	5.37	5.19	5.61	5.81	5.76	5.23	5.16	5.31	5.08	4.94	5.13	5.37	5.33
1998	5.08	5.27	5.13	5.34	5.23	5.31	5.44	5.66	4.83	4.76	5.09	4.81	5.16
1999	4.83	5.28	5	5	5.36	5.38	5.56	5.53	5.68	6.24	6.01	6.14	5.50
2000	6.39	6.31	6.17	6.2	6.21	6.08	6.03	5.94	5.81	5.79	5.63	5.32	5.99

Source: Bank of Canada, ***Department of Monetary and Financial Analysis***.

Table A1.4: Reserves addition estimates - both provinces

	Table A1.4.1 Crude oil in Saskatchewan Reserve, Production, and Addition, 1971-1998				Table A1.4.2 Crude oil in Alberta Addition, 1951-1985	
Year	Remaining Rsrv. (000 m^3/year)	Yearly Prod (000 m^3)	Addition (000 m^3)	Addition from New Discoveries	Addition (000 m^3)	Addition from New Discoveries
1961	n/a	n/a	n/a	n/a	57700	1700
1962	n/a	n/a	n/a	n/a	44600	2900
1963	n/a	n/a	n/a	n/a	56400	14600
1964	n/a	n/a	n/a	n/a	348500	9500
1965	n/a	n/a	n/a	n/a	68800	28600
1966	n/a	n/a	n/a	n/a	140900	89100
1967	n/a	n/a	n/a	n/a	95100	57200
1968	n/a	n/a	n/a	n/a	119700	62000
1969	n/a	n/a	n/a	n/a	54500	40500
1970	n/a	n/a	n/a	n/a	36900	8400
1971	137000	14052.5	n/a	9173	21900	14000
1972	127000	13724	3724	5782	20000	10800
1973	122000	13651	8651	3278	9300	5100
1974	116000	11753	5753	6497	38400	4300
1975	128000	9380.5	21380.5	222	7000	1600
1976	123000	8869.5	3869.5	2007	-18600	2500
1977	119000	9745.5	5745.5	2939	19100	4800
1978	117000	9636	7636	5577	24400	24900
1979	118000	9380.5	10380.5	10306	34300	19200
1980	118000	9307.5	9307.5	11168	22700	9000
1981	117000	7409.5	6409.5	2488	32600	15000
1982	109707	8139.5	846.5	6062	6900	16800
1983	114295	9526.5	14114.5	3928	64100	21400
1984	115458	10804	11967	3838	41200	29100
1985	122937	11607	19086	8071	64000	32700
1986	106296	11680	-4961	669	n/a	n/a
1987	106146	12081.5	11931.5	3588	n/a	n/a
1988	112838	12227.5	18919.5	1297	n/a	n/a
1989	111909	11753	10824	672	n/a	n/a
1990	116896	12227.5	17214.5	4986	n/a	n/a
1991	110336	12420	5860	1334	n/a	n/a
1992	119515	13370	22549	267	n/a	n/a
1993	131213	14970	26668	2621	n/a	n/a
1994	135283	17190	21260	3449	n/a	n/a
1995	148202	18750	31669	2477	n/a	n/a
1996	156808	20940	29546	2989	n/a	n/a
1997	176631	23460	43283	1279	n/a	n/a
1998	180928	23150	27447	999	n/a	n/a

Source:
(1)Saskatchewan Energy and Mines*, **Reservoir Annual***, 1971-1999, p. C-1.
(2)ERCB ***Annual report***, 1985, p. 7-2.
(3)***Statistic Canada,*** 26-213-XPB,1985 to 1999.

Table A1.5: Raw data - Saskatchewan

year	sd	sg	sl	drill	geo	land	oil intent	gas intent	xdo	xgo	xlo
1961	0	0	0	139196	1017587	896399	0.95	0.05	132574.27	969176.414	853753.71
1962	0	0	0	222926	1192217	1622163	0.86	0.14	190819.5	1020511.7	1388536.5
1963	0	0	0	304000	2178309	1052738	0.72	0.28	218380.84	1564806.09	756243.03
1964	0.67	0.24	0.09	533485	3900630	2132938	0.96	0.04	509862.77	3727912.9	2038493.1
1965	0.63	0.18	0.19	581397	2513882	2661654	0.86	0.14	500497.89	2164085.8	2291295.7
1966	0.55	0.14	0.31	614635	1182717	3250706	0.90	0.10	551651.7	1061520.49	2917597.4
1967	0.38	0.26	0.36	555024	2393550	3354909	0.85	0.15	469875.51	2026345.24	2840218.3
1968	0.41	0.2	0.38	550740	2017582	1548242	0.75	0.25	415620.91	1522587.61	1168395.9
1969	0.39	0.37	0.24	610155	1073762	1895539	0.74	0.26	450001.33	791920.567	1397997.1
1970	0.32	0.36	0.32	340339	511891.5	1767087	0.57	0.43	192324.52	289268.754	998576.91
1971	0.31	0.35	0.34	326859	367473.2	1179914	0.36	0.64	117529.35	132132.949	424263.67
1972	0.36	0.22	0.42	243988	542504.9	1769451	0.33	0.67	81383.081	180954.777	590207.76
1973	0.41	0.21	0.38	287404	443588.4	706652	0.45	0.55	130102.81	200804.646	319888.89
1974	0.5	0.27	0.23	142925	155319.5	479929	0.16	0.84	23389.315	25417.5847	78539.004
1975	0.4	0.18	0.42	116749	378059	537162	0.09	0.91	10371.732	33585.9263	47720.285
1976	0.48	0.07	0.45	132164	400963.7	537162	0.56	0.44	73457.089	222855.976	298555.11
1977	0.54	0.17	0.29	200858	595051.8	170437	0.76	0.24	152839.99	452796.5	129691.7
1978	0.73	0.16	0.11	357449	1329437	134542	0.91	0.09	323806.92	1204313.11	121879.16
1979	0.52	0.16	0.32	454910	2287423	150740	0.95	0.05	431059.45	2167496.21	142836.89
1980	0.56	0.19	0.25	786255	2752416	227372	0.85	0.15	669278.35	2342921.74	193544.4
1981	0.45	0.19	0.36	459512	1954440	124776	0.59	0.41	268948.39	1143917.84	73030.374
1982	0.3	0.24	0.45	310062	1172027	123962	0.95	0.05	293154.43	1108117.19	117202.4
1983	0.21	0.18	0.61	432175	2072641	240970	0.58	0.42	248794.29	1193177.91	138721.58
1984	0.46	0.18	0.36	727057	2127054	434292	0.51	0.49	367481.21	1075091.42	219507.16
1985	0.5	0.22	0.28	889701	4062385	717404	0.55	0.45	491806.42	2245592.81	396564.39

year	xdg	xgg	xlg	po	pg	ro	rg	yo	yg
1961	6,622.13	48,410.70	42,645.29	17.36	0.0033	252694	80049800	3555	0
1962	32,106.10	171,704.97	233,626.50	18.44	0.0035	255755	80647400	3061	597600
1963	85,619.06	613,502.70	296,495.00	18.85	0.0037	270449	85703300	14694	5055900
1964	23,622.33	172,717.02	94,444.92	19.25	0.0039	283982	85703300	13533	0
1965	80,899.01	349,796.49	370,358.30	19.20	0.0042	299857	88447300	15875	2744000
1966	62,983.30	121,196.15	333,108.60	19.05	0.0043	303142	88460100	3285	12800
1967	85,148.59	367,204.57	514,690.70	19.20	0.0047	309649	89011400	6507	551300
1968	135,118.59	494,994.07	379,846.10	18.89	0.0045	321621	89269600	11972	258200
1969	160,153.77	281,841.53	497,541.90	18.81	0.0044	331990	93223100	10369	3953500
1970	148,013.98	222,622.77	768,510.10	18.72	0.0041	335481	107310600	3491	14087500
1971	209,329.95	235,340.22	755,650.30	20.65	0.0044	344654	110321700	9173	3011100
1972	162,604.52	361,550.14	1,179,243.00	20.69	0.0046	350436	111131100	5782	809400
1973	157,301.39	242,783.76	386,763.10	25.80	0.0048	353714	113354100	3278	2223000
1974	119,535.98	129,901.88	401,390.00	45.12	0.0052	360211	116759500	6497	3405400
1975	106,377.37	344,473.07	489,441.70	57.73	0.0060	360433	116759500	222	0
1976	58,707.31	178,107.73	238,606.90	49.88	0.0070	362440	116970600	2007	211100
1977	48,017.81	142,255.28	40,745.30	59.45	0.0093	365379	117101300	2939	130700
1978	33,642.48	125,124.18	12,662.84	71.62	0.0111	370956	117900600	5577	799300
1979	23,850.35	119,926.73	7,903.11	77.63	0.0159	381262	117945000	10306	44400
1980	116,976.15	409,494.75	33,827.60	92.44	0.0159	392430	133798400	11168	15853400
1981	190,563.21	810,522.27	51,745.63	110.44	0.0175	394918	133800000	2488	1600
1982	16,907.57	63,910.24	6,759.60	145.87	0.0186	400980	133800000	6062	0
1983	183,380.41	879,463.36	102,248.40	172.82	0.0373	404908	137584600	3928	3784600
1984	359,575.49	1,051,962.71	214,784.80	173.13	0.0497	408746	138914400	3838	1329800
1985	397,894.98	1,816,792.26	320,839.60	194.22	0.0565	416817	139478000	8071	563600

Source: Various (see page 46).

Table A1.6: Raw data - Alberta

Year	sd	sg	sl	drill	geo	land	oil intent	gas intent	xdo	xgo	xlo
1961	0	0	0	1011598.3	10146412	31232547.7	0.42	0.59	419799.	4210625	12961091
1962	0	0	0	1035745.5	9873710.	31232547.7	0.45	0.55	464965.	4432491	14020869
1963	0	0	0	1091504.7	10571332	31232547.7	0.58	0.42	635545.	6155322	18185638
1964	0.4	0.27	0.33	916965.2	10566694	31232547.7	0.53	0.47	489498.	5640758	16672694
1965	0.48	0.25	0.26	1038251.8	8990861.	34374316.3	0.63	0.37	654629.	5668841	21673404
1966	0.44	0.24	0.32	948718.35	15126153	32258206	0.63	0.37	599270.	9554631	20376316
1967	0.36	0.21	0.44	969431.64	18581765	31760119.5	0.75	0.25	731082.	1401315	23951413
1968	0.27	0.25	0.47	1354897	15144181	30471133.8	0.70	0.30	953839.	1066141	21451506
1969	0.29	0.34	0.37	1376361	14039622	29022368.9	0.68	0.32	940641.	9595046	19834649
1970	0.32	0.33	0.35	1294658.7	12492987	27625691.7	0.36	0.64	471921.	4553874	10069965
1971	0.29	0.33	0.38	1226713	9359570.	29253724.1	0.47	0.53	573746.	4377568	13682272
1972	0.28	0.3	0.42	1398841.8	9429466.	31659069.9	0.29	0.71	411337.	2772790	9309537.
1973	0.51	0.34	0.15	1649993	8854159	32310182	0.32	0.68	525049	2817507	10281514
1974	0.56	0.32	0.12	1583000	12861411	31430000	0.26	0.74	404241	3284339	8026087.
1975	0.5	0.25	0.25	1458000	9720985.	30830000	0.23	0.77	335394.	2236189	7092049.
1976	0.41	0.33	0.26	1958000	13366857	30598000	0.17	0.83	333231.	2274904	5207472.
1977	0.53	0.22	0.25	1958000	19779330	30520000	0.25	0.75	479923.	4848090	7480724.
1978	0.56	0.22	0.22	2320000	28974342	26217000	0.30	0.70	703508.	8786078	7949952
1979	0.59	0.22	0.19	2777000	26726314	30045000	0.38	0.62	1057872	1018114	11445365
1980	0.49	0.18	0.32	3073000	30710007	32045000	0.36	0.64	1114286	1113561	11619690
1981	0.59	0.14	0.28	3168000	20713809	31777000	0.41	0.59	1290475	8437706	12944264
1982	0.47	0.15	0.37	2300000	17193716	30055000	0.54	0.46	1247984	9329339	16307894
1983	0.38	0.15	0.47	1817000	17189425	29340000	0.71	0.29	1298934	1228835	20974534
1984	0.45	0.17	0.38	2408000	20181638	28534000	0.74	0.26	1773336	1486246	21013442
1985	0.52	0.19	0.29	2868000	20998533	28501000	0.78	0.22	2230140	1632833	22162214

Year	xdg	xgg	xlg	po	pg	ro	rg	yo	yg
1961	591798	5935786	18271457	14.84	0.0040	993445.7	1362664000	7658.7	86267000
1962	570780	5441218.7	17211678	14.32	0.0041	1009471	1376973000	16025.5	14309000
1963	455959	4416009	13046910	15.89	0.0044	1038411	1426354000	28939.7	49381000
1964	427467	4925935.4	14559853	16.11	0.0046	1075038	1446569000	36626.6	20215000
1965	383622	3322019.2	12700912	16.16	0.0053	1142022	1489542000	66984.2	42973000
1966	349448	5571521.6	11881890	16.20	0.0053	1188682	1500736000	46660.4	11194000
1967	238349	4568608.5	7808707	16.09	0.0053	1223536	1567167000	34853.9	66431000
1968	401057	4482762.9	9019627	16.22	0.0053	1241217	1592097000	17680.7	24930000
1969	435720	4444575.5	9187720	16.11	0.0057	1252434	1642887000	11217.6	50790000
1970	822737	7939112	17555727	16.32	0.0057	1255768	1665997000	3333.7	23110000
1971	652967	4982001.5	15571452	17.90	0.0057	1264111	1688370000	8343.4	22373000
1972	987504	6656675.9	22349532	17.92	0.0058	1267083	1745684000	2971.1	57314000
1973	1124944	6036652.1	22028668	21.89	0.0065	1278316	1789105000	11233.6	43421000
1974	1178759	9577070.7	23403913	36.72	0.0108	1282169	1839146000	3852.5	50041000
1975	1122606	7484796.1	23737950	45.79	0.0226	1283513	1861670000	1344.4	22524000
1976	1624768	11091952	25390528	53.38	0.0363	1289068	1909639000	5555.1	47969000
1977	1478077	14931240	23039276	64.11	0.0464	1298983	1974578000	9914.5	64939000
1978	1616491	20188263	18267048	76.60	0.0551	1327888	2017695000	28905.7	43117000
1979	1719128	16545172	18599635	86.18	0.0639	1347855	2047146000	19966.5	29451000
1980	1958714	19574393	20425310	109.48	0.0887	1360041	2069674000	12185.7	22528000
1981	1877525	12276102	18832736	131.70	0.0932	1369042	2082050000	9001.5	12376000
1982	1052016	7864376.3	13747106	170.35	0.1018	1390142	2084942000	21100.1	2892000
1983	518066	4901075.6	8365466	195.72	0.1039	1413701	2087883000	23559.1	2941000
1984	634664	5319169.2	7520558	194.72	0.1071	1428959	2089942000	15257.7	2059000
1985	637860	4670194.1	6338786	214.22	0.1012	1430325	2090336000	1365.6	394000

Source: Various (see page 46).

Notes for Table A1.5 and Table A1.6:

- **sd =** The share of drilling input of the total inputs, indicate by the ratio of drilling expenditure of the total exploration expenditures.
- **sg =** The share of geophysics input of the total inputs, indicate by the ratio of geophysics expenditure of the total exploration expenditures.
- **sl =** The share of land input of the total inputs, indicate by the ratio of land expenditure of the total exploration expenditures.
- **drill =** Total meters of wells drilled yearly.
- **geo =** Total man-hours of geophysicists work yearly.
- **land =** Total hectares of land under exloration.
- **oil intent =** Oil success rate by exploratory oil wells, where the oil success rate is the ratio of successful oil wells under exploration (including the 'both oil and gas finding' category) over total wells drilled during the year.
- **gas intent =** Gas success rate by exploratory gas wells, where the gas success rate is the ratio of successful gas wells under exploration over total wells drilled during the year.
- **xdo =** Total meters of wells drilled by oil intent.
- **xgo =** Total man-hours of geophysics by oil intent.
- **xlo =** Total hectares of land acquisition by oil intent.
- **xdg =** Total meters of wells drilled by gas intent.
- **xgg =** Total man-hours of geophysics by gas intent.
- **xlg =** Total hectares of land acquisition by gas intent.
- **po =** Average wellhead price of all types of crude oil, yielded by dividing the total value of crude oil production over the total crude oil production.
- **pg =** Average wellhead price of gas, yielded by dividing the total value of gas production over the total gas production.
- **ro =** Cumulative oil discoveries, initial recoverable reserves - yearly aggregate.
- **rg =** Cumulative gas discoveries, initial recoverable reserves - yearly aggregate.
- **yo =** Oil discoveries, estimated by initial recoverable reserves per discovery year.
- **yg =** Gas discoveries, estimated by initial recoverable reserves per discovery year.